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APPLICATIONS OF REMOTE SENSING TO WATER RESOURCES

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16. ABSTRACT

In FY-77 the Marshall Space Flight Center Data Management Program activities largely centered around the analyses of selected far-term (1985 and beyond) Office of Applications (OA) objectives, with the intent of determining if significant data-related problems would be encountered and to develop alternative solutions to any potential problems. One far-term OA objective selected for analysis was Water Availability Forecasting. MSFC scheduled a brief overview in FY-77 of the objective -- primarily a fact-finding study to allow MSFC Data Management personnel to gain adequate background information to perform subsequent data system analyses. ECOsystems International, Incorporated, provided a significant part of this background material. This report, "Applications of Remote Sensing to Water Resources," by ECOsystems includes discussions on some of the larger problems currently encountered in water measurement, the potential users of water availability forecasts, projected demands of users, current sensing accuracies, required parameter monitoring, status of forecasting modeling, and some measurement accuracies likely to be achievable by 1980 and 1990.

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APPLICATIONS OF REMOTE SENSING TO WATER RESOURCES

Overview of the Water Resources Field

A principal socieconomic significance of water resources is the fact that water is becoming scarce. There are two possible sources of water. The one currently used is natural precipitation. The other is represented by new technologies, such as desalinization; it is as yet economically non-competitive.

The overall supply-demand situation for the U.S. is depicted in Figure 1. By the year 1990 the total precipitation, less the natural evaporation, divided by the estimated population, will provide a disposable per-capita daily quantity of water equal to approximately one-third of the withdrawal demand - assuming that the latter continues to grow at the past historical rate. The situation calls for significantly increased efficiency of utilization of the natural water supply.

FIGURE 1

WATER RESOURCES, DEMAND-SUPPLY PROJECTION-1990

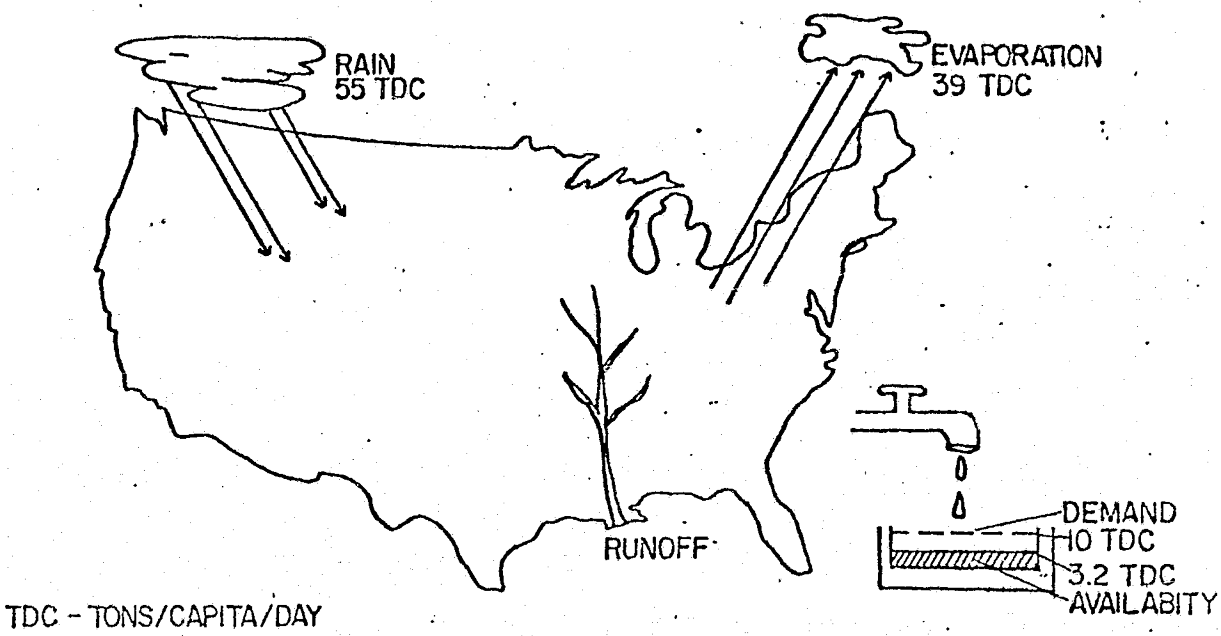

FIGURE 2

PRINCIPAL REQUIREMENTS AND CONCERNS OF WATER USERS

THE EFFECTS OF WATER

Excess Water
- Floods
- Avalanches
- Wetlands
  - Reclamation
  - Mgmt.

Waterborne Substances
- Toxicants
- Disease Vectors
- Eutrophicants
- Inhibitors
- Aesthetics
- Thermal
- Sedimentary

Hydrogeological Effects
- Landslides
- Mudslides
- Soil Erosion & Sedimentation
- Subsidence
- Drought/Desertification
- Salt Water Intrusions

DEMANDS FOR WATER

Consumptive Uses
- Agricultural
  - Irrigation
  - Livestock
- Industrial
  - Process
  - Cooling
- Domestic
  - Sanitary
  - Consumptive
- Municipal
  - Sewage Processing
  - Aesthetic
  - Fire Fighting

Flow Uses
- Hydropower
- Pollution
- Dilution/Entrainment

On-Site Uses
- Inland Navigation
- Recreation
- Commercial Fishing

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Water, like any natural phenomenon, can be beneficial or damaging, depending upon its impact on the users, the degree of control, and the user's viewpoint.

For example, the excess water on a wetland can be viewed simultaneously as a nuisance by farmers or developers, and as a boon by sportsmen and conservationists. Floods can be damaging to homeowners, but beneficial to farmers by virtue of the fertilizing qualities of the deposited sediment.

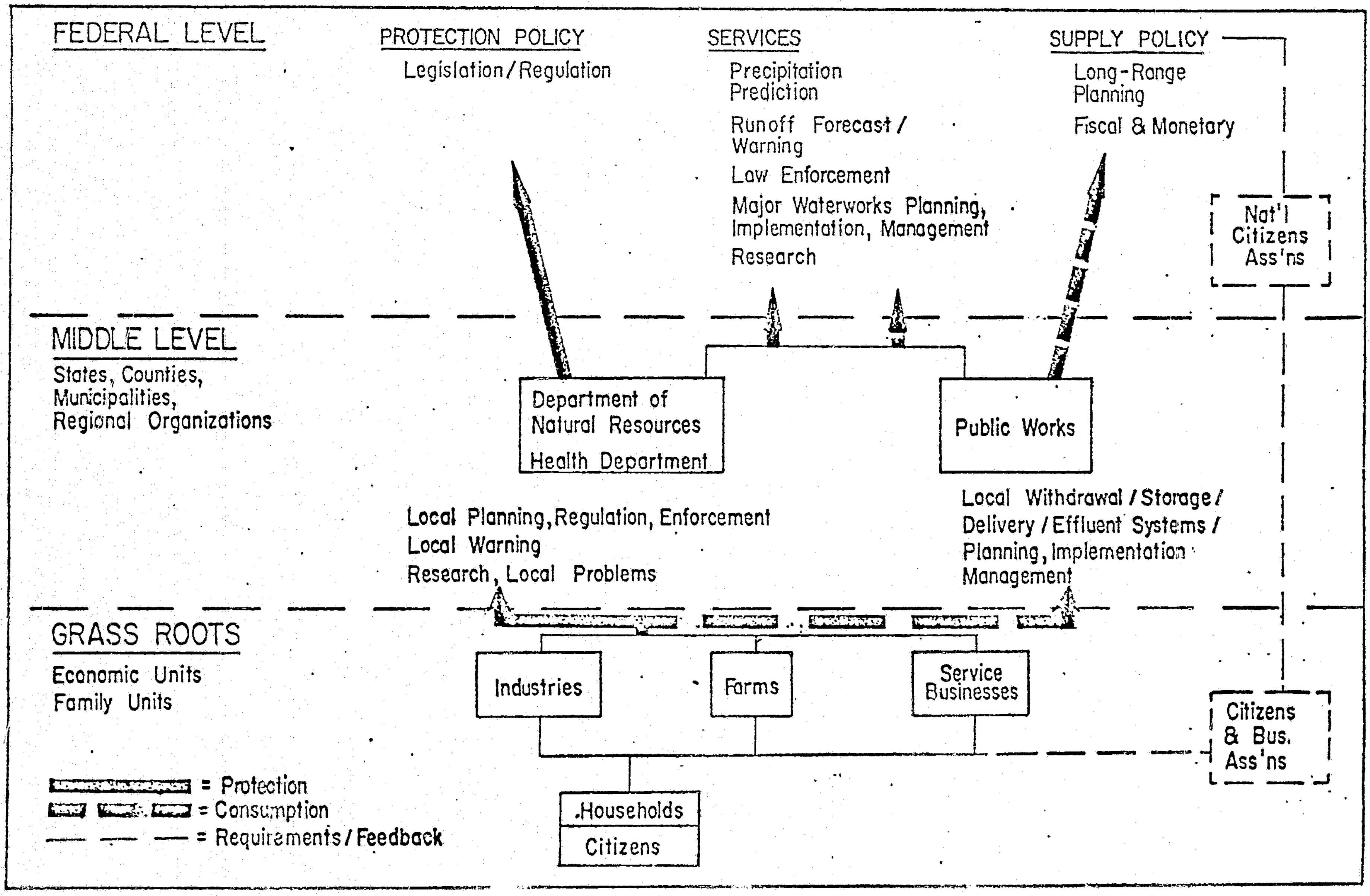
The major impact of water resources upon the public is summarized as follows:

EFFECTS OF WATER	DEMANDS FOR WATER
- Excess Water	- Consumptive Uses
- Waterborne Substances	- Flow Uses
- Hydrogeological Effects	- On-site Uses

It is presented in more detail in Figure 2.

The general user structure is shown in Figure 3. The ultimate user of water is the U.S. citizenry. Citizens group into units to efficiently explicate the tasks of everyday life and economic production, and into politically-oriented associations for making their wishes known to authorities.

The first-level grouping are the "Grass Roots" users. Its major interests are twofold: 1) protection against damages from water, and 2) provision of supply adequate to meet the needs of households, agriculture and industry.



USER INTERESTS, FUNCTIONS, INTERRELATIONSHIPS

FIGURE 3

At the middle-level are state and local entities to whom the citizenry delegates the task of providing for, managing and regulating their local needs.

Agencies at the Federal level develop and provide policy, guidance and services whose scope and data requirements transcend the local level's geographic domain and capabilities.

National citizen's organizations provide their viewpoints and needs to local, state and the federal legislative and policy-making level.

The principal drivers of the supply and demand of water

Practically all the fresh water supply is generated by precipitation. In the U.S., 70% of this input is lost through evaporation and evapotranspiration before reaching exploitable concentrations.

The remaining 30% goes into streamflow and to replenish groundwater supplies. One third of this, or approximately 10% of the total supplies, is withdrawn by human activities. A little over 40% of this one-third is consumed, as shown in Figure 4.

Thus, the efficiency of utilization of the total supply is: in terms of withdrawals, 10%: in terms of net use, 4%.

In a broad sense, water is never "lost" since it eventually returns into circulation. The question is the time lapse required to so return, i.e. whether in useful time for the purpose at hand. *Consumption* denotes the amount of water which is *dissipated for the use-*

FIGURE 4

U.S. SUPPLY AND DEMAND OF WATER-1977

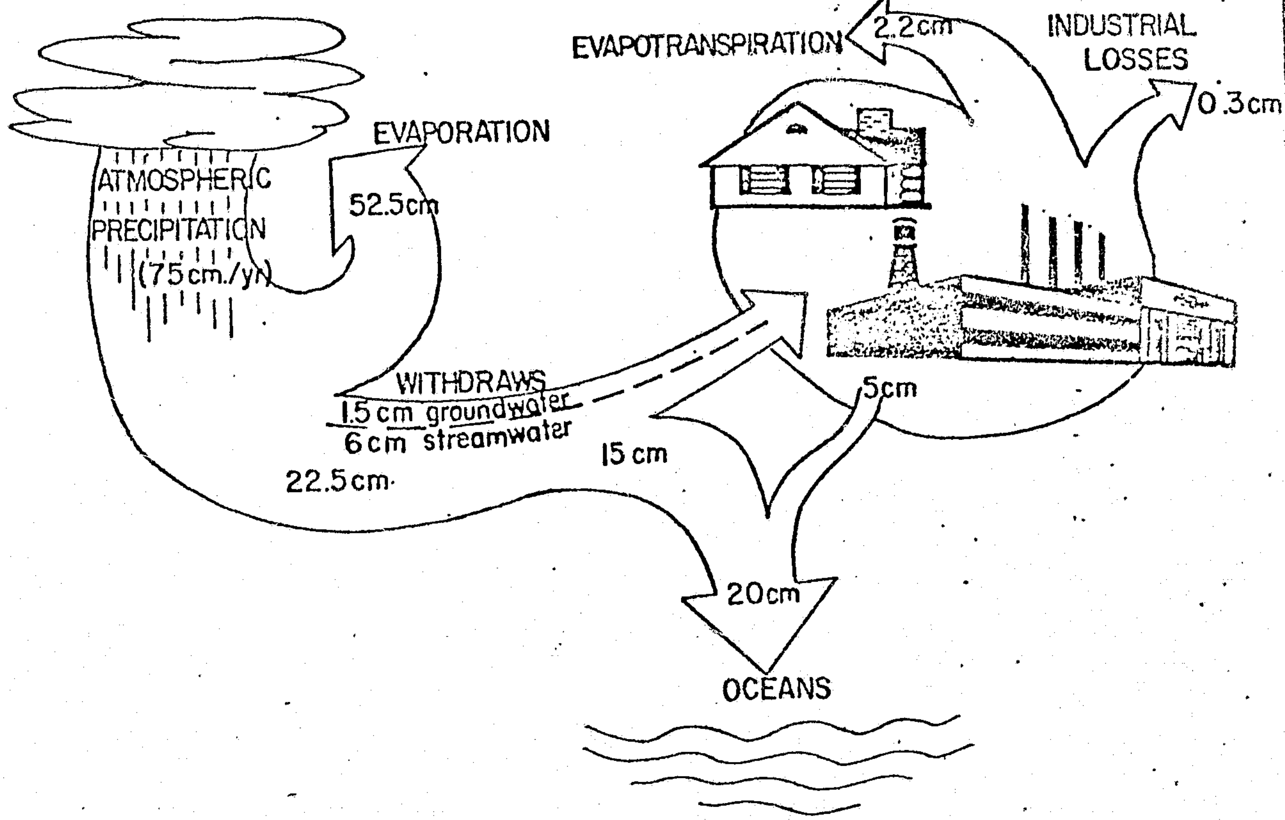
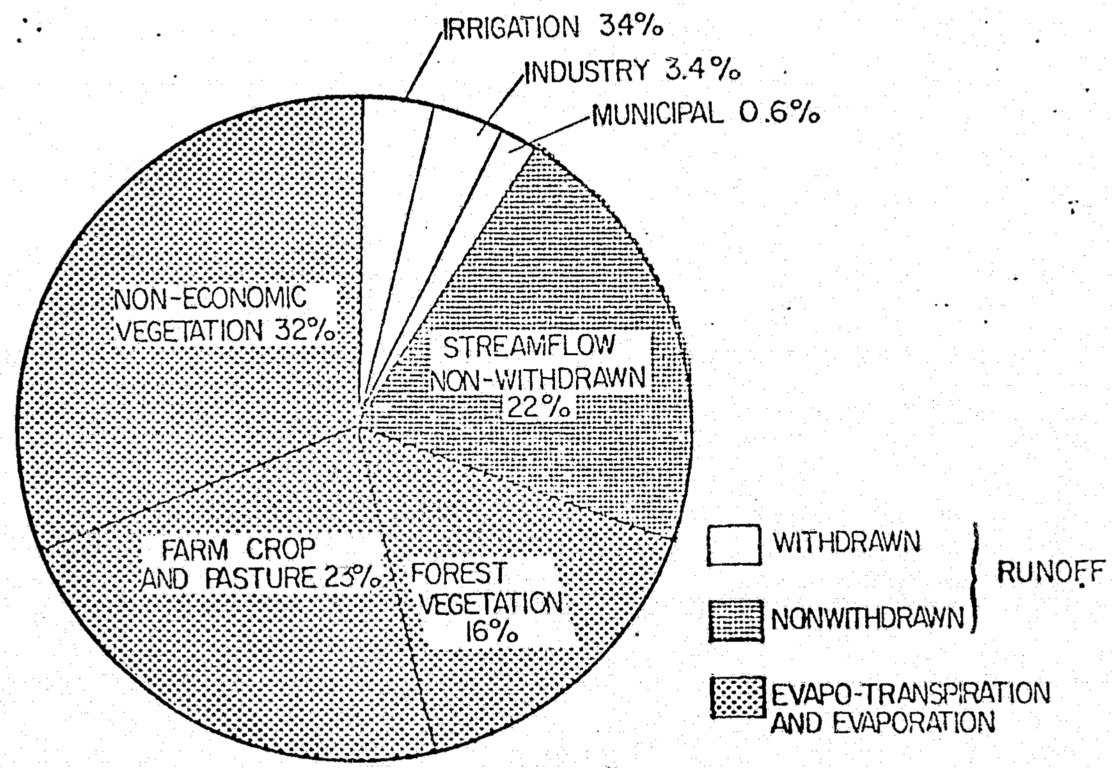


FIGURE 5

ALLOCATION OF WATER DEMAND (1970)



TOTAL SUPPLY : 5700 km.^{3}/yr. 570 Million ha-m

ful time being: whether by incorporation into products such as foods, or by evaporation from irrigation, or similar dissipative uses.

Withdrawals designate the amounts of water taken from the supply and which can be *returned to the cycle in useful time:* e.g. industrial cooling water withdrawn from a stream and dumped further downstream.

As shown in Figure 5, approximately 92% of the fresh water withdrawn in the U.S. (which, as mentioned earlier, is approximately 10% of the supply) is utilized in equal parts by agricultural and industrial activities. Urban and household use accounts for only 8% of all withdrawals.

The continuing growth of water consumption portends an era of water scarcity. This has already been illustrated for the U.S. as a whole in Figure 1. A more detailed regional vision is offered by Figures 6, 7, 8 which contrast the historical growth in regional consumption with the present and maximum regulated flow available within each region.

By regulated flow is meant the water supply which is sufficiently reliable to match the demand over a specified fraction of time. 98% regulated flow is a conventional Corps of Engineers specification: it means that water scarcity will not occur more than 2% of the time, or one week per year on the average. Available regulated flow refers to the currently installed reservoir capacity: maximum regulated flow refers to the maximum reservoir capacity which is practically implementable within the region. Note that in some regions, e.g. Rio Grande, the consumption already exceeds the regulated flow. These regions fill the deficit by importation of water from neighboring regions.

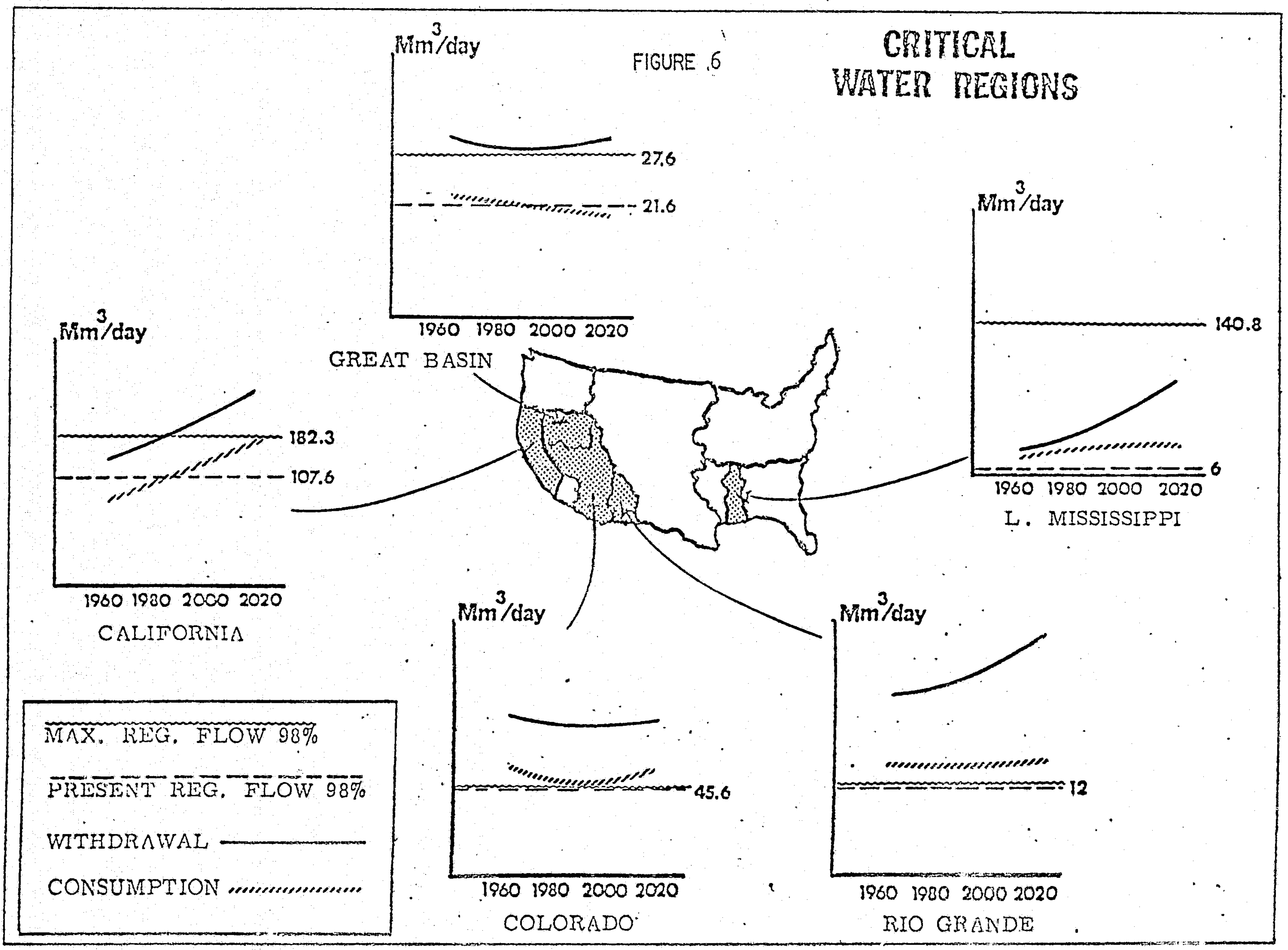


FIGURE 6
CRITICAL WATER REGIONS
Mm³/day
27.6
21.6
1960 1980 2000 2020
GREAT BASIN
Mm³/day
182.3
107.6
1960 1980 2000 2020
CALIFORNIA
Mm³/day
140.8
6
1960 1980 2000 2020
L. MISSISSIPPI
Mm³/day
45.6
1960 1980 2000 2020
COLORADO
Mm³/day
12
1960 1980 2000 2020
RIO GRANDE
MAX. REG. FLOW 98%
PRESENT REG. FLOW 98%
WITHDRAWAL
CONSUMPTION

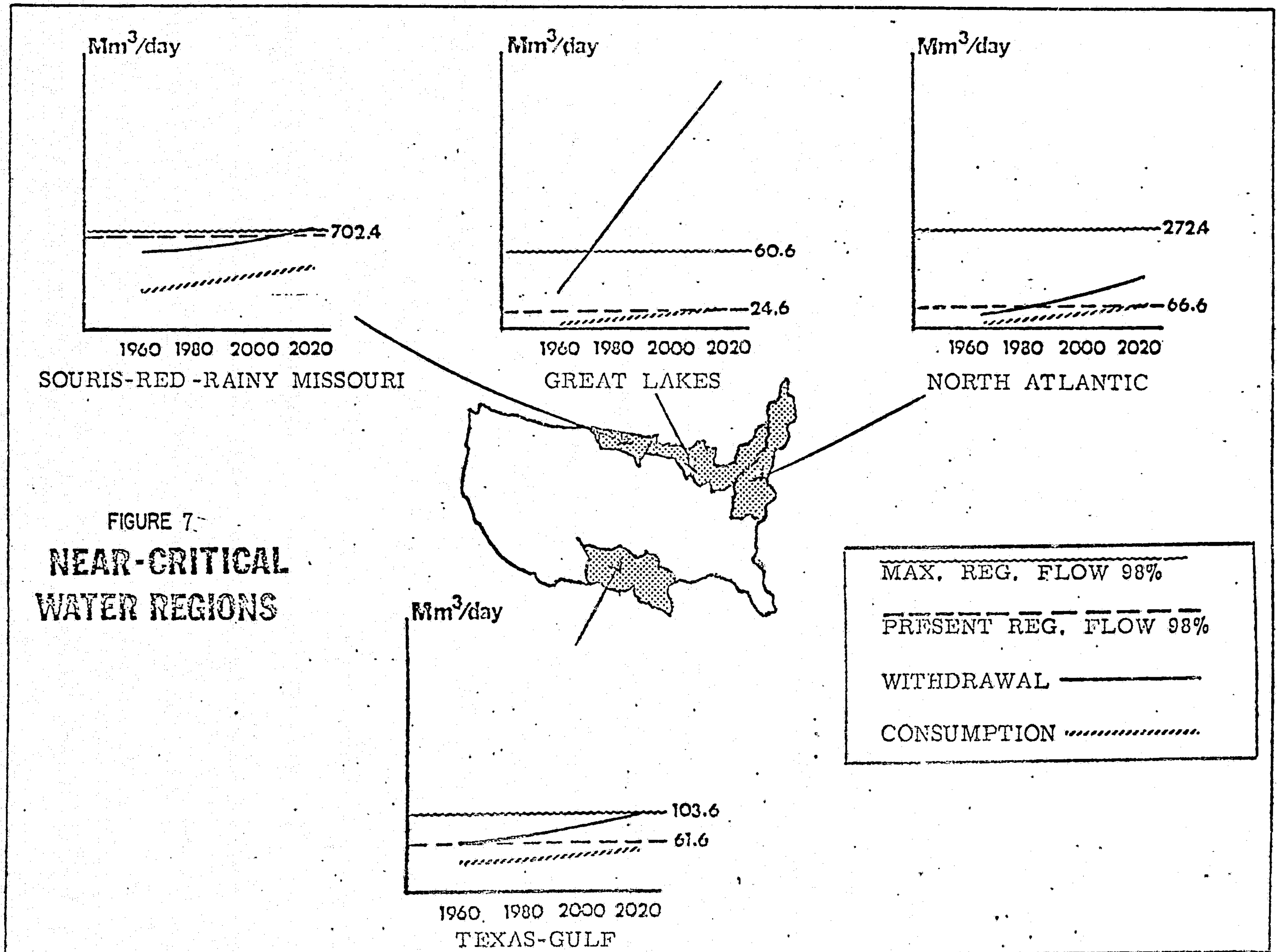


FIGURE 7

NEAR-CRITICAL WATER REGIONS

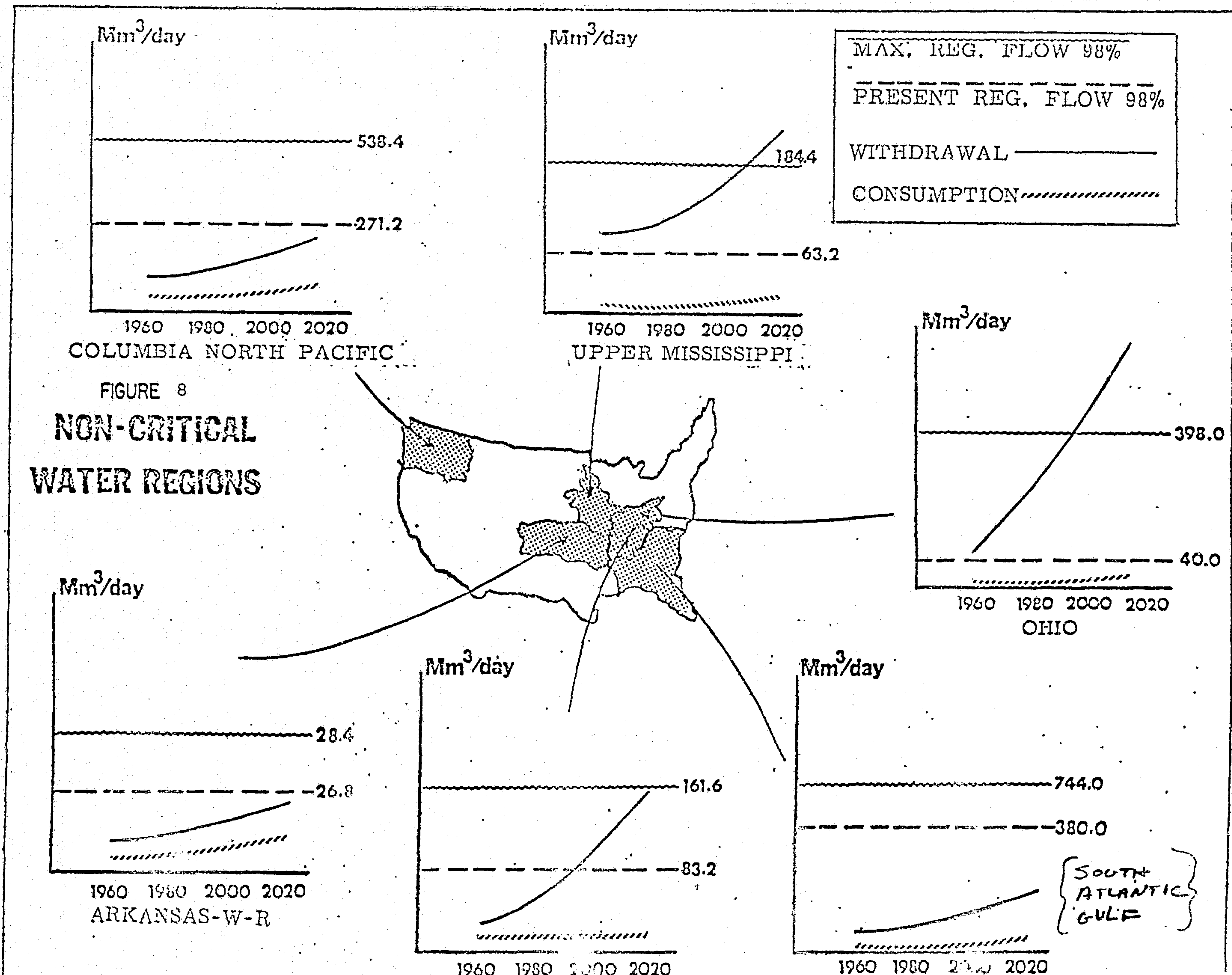


FIGURE 8

NON-CRITICAL WATER REGIONS

Figure 9 depicts by region, the sources of water supply. Note that groundwater is nothing more than rainwater accumulated in natural underground reservoirs. These increase the efficiency of utilization of rain water by capturing part of the water which is otherwise lost by infiltration in the soil. However, excessive withdrawals eventually deplete them: the recharge period can last from a few years to decades. Thus Figure 10 confirms the fact that ultimately all currently used water originates from precipitation.

In contrast to some foreign Countries, notably England, in the United States there exists no centralized Agency concerned with water: the administrative planning and management of water resources is fragmented among thousands of Federal, State, Local, agencies, Inter-State Commissions, User Cooperatives and private concerns.

Concern for the impending scarcity of water is as yet not felt by the Public or by Congress. The situation is reminiscent of the energy outlook in the sixties: oil was then thought to be so abundant, cheap and inexhaustible as to cause the curtailment of fusion energy research.

Nevertheless, it is believed that the water scarcity problem will come to the fore no later than the early eighties, after some significant water - deficiency event will have struck the public's consciousness.

SOURCES OF WATER BY REGIONS

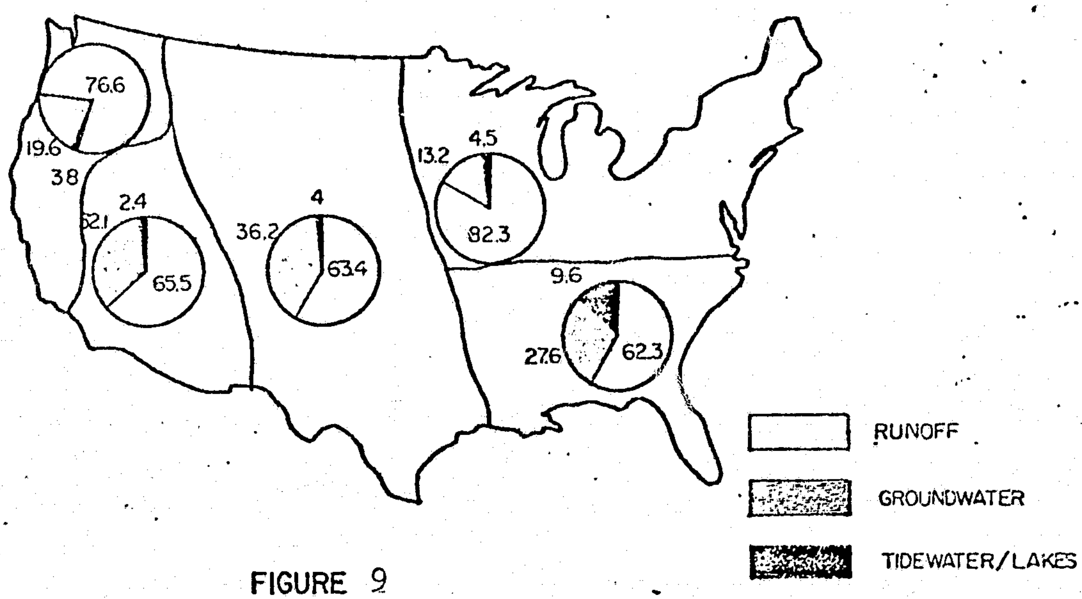
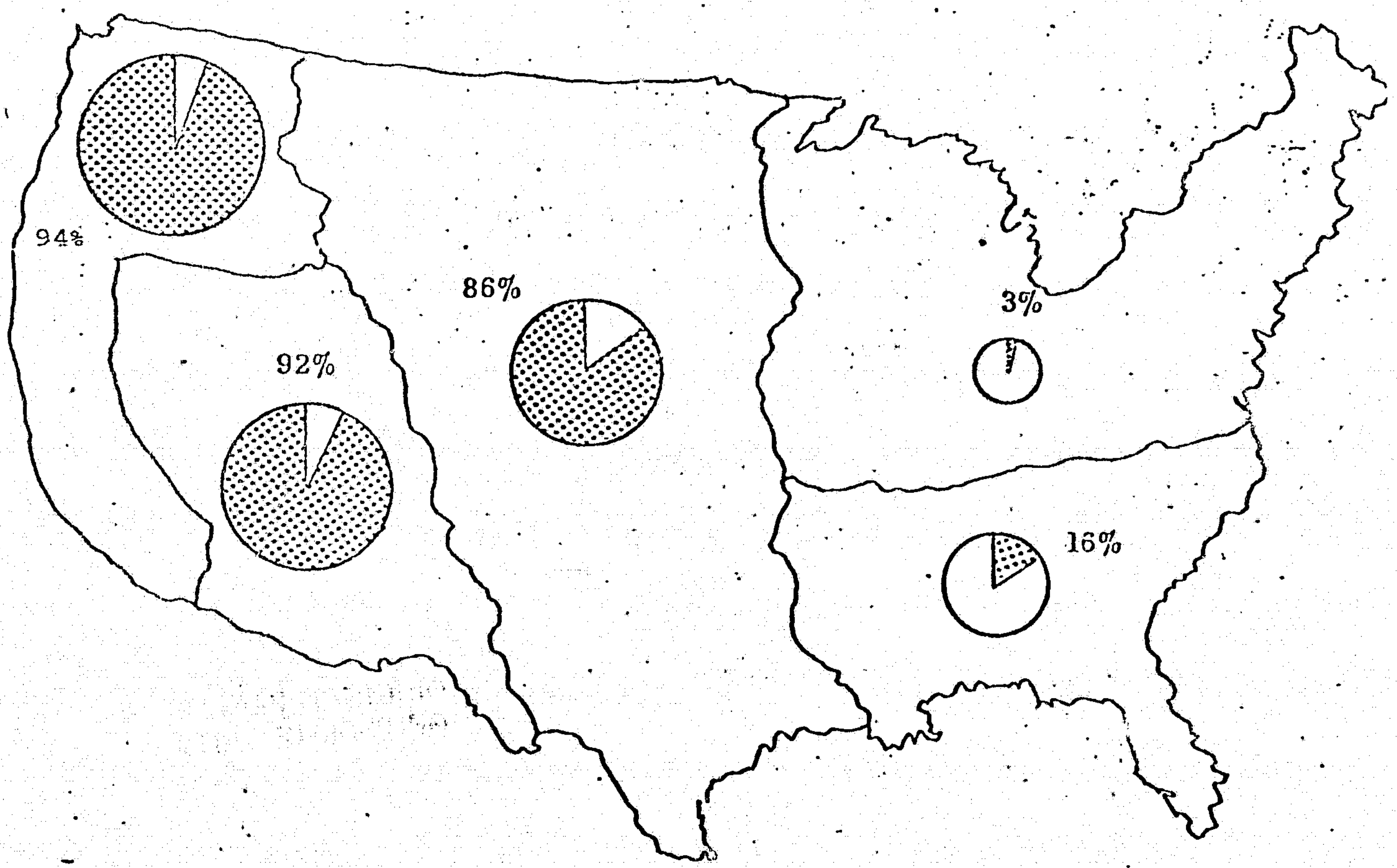


FIGURE 9

FIGURE 10

IRRIGATION WITHDRAWALS AS A PERCENT OF TOTAL WITHDRAWALS, 1970



Remote Sensing Applications

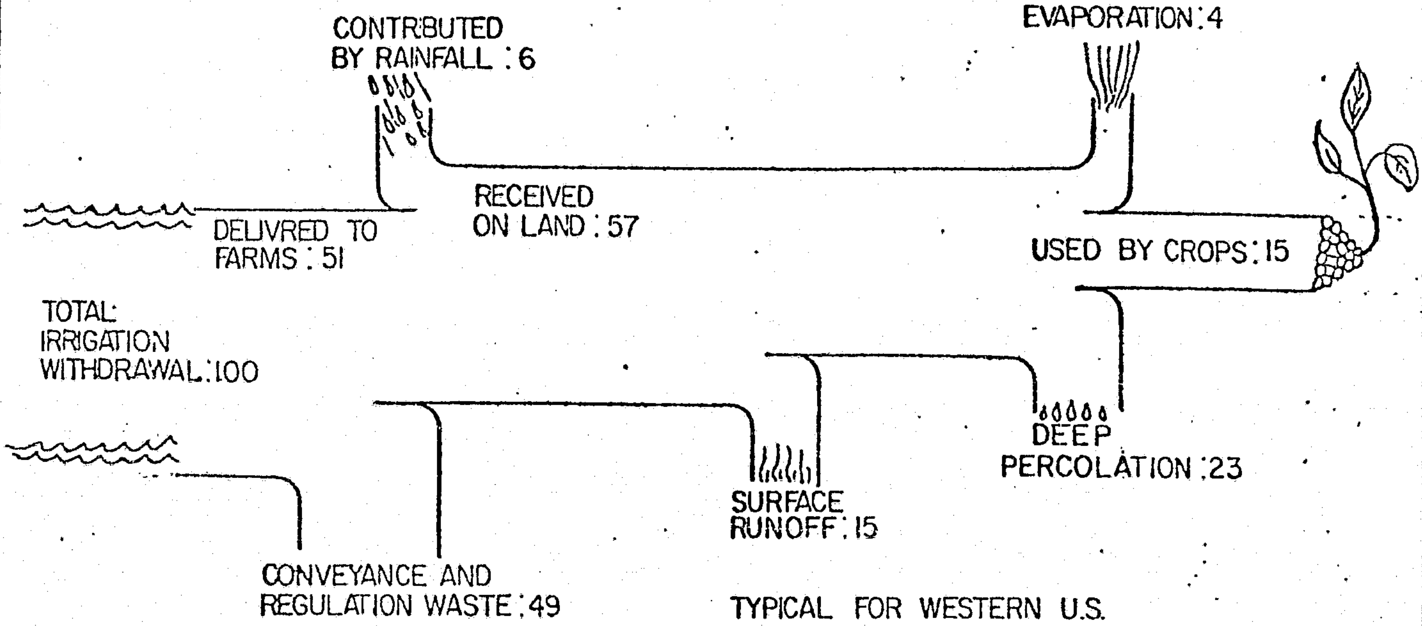
Irrigation

Irrigation water accounts for 46% of all withdrawals. Figure 11 shows that irrigation represents the major withdrawal in the Western and Central States. Figure 12 indicates that irrigation water is generally characterized by heavy conveyance losses: on the average, approximately only half of the withdrawn water reaches the irrigation site. Approximately 70% of this water is lost through surface runoff, percolation into the ground and evaporation: thus, typically only 15% of the withdrawn water reaches the crops. The problem with irrigation water is that its use is primarily consumptive.

Irrigation water is needed to supplement deficiencies in precipitation water. The effect of too much water can be as deleterious as that of insufficient water. The yield as a function of applied water varies significantly with the type of crop, the soil characteristics, and the climate.

There exists thus a significant "leverage" between water consumed by crops and total water withdrawn from the source: relatively small changes in crop water demand can cause notable variations in the quantity of total irrigation water withdrawals.

Thus improved management of irrigation water can have *major impact on water conservation*. This function is *amenable to remote sensing*.

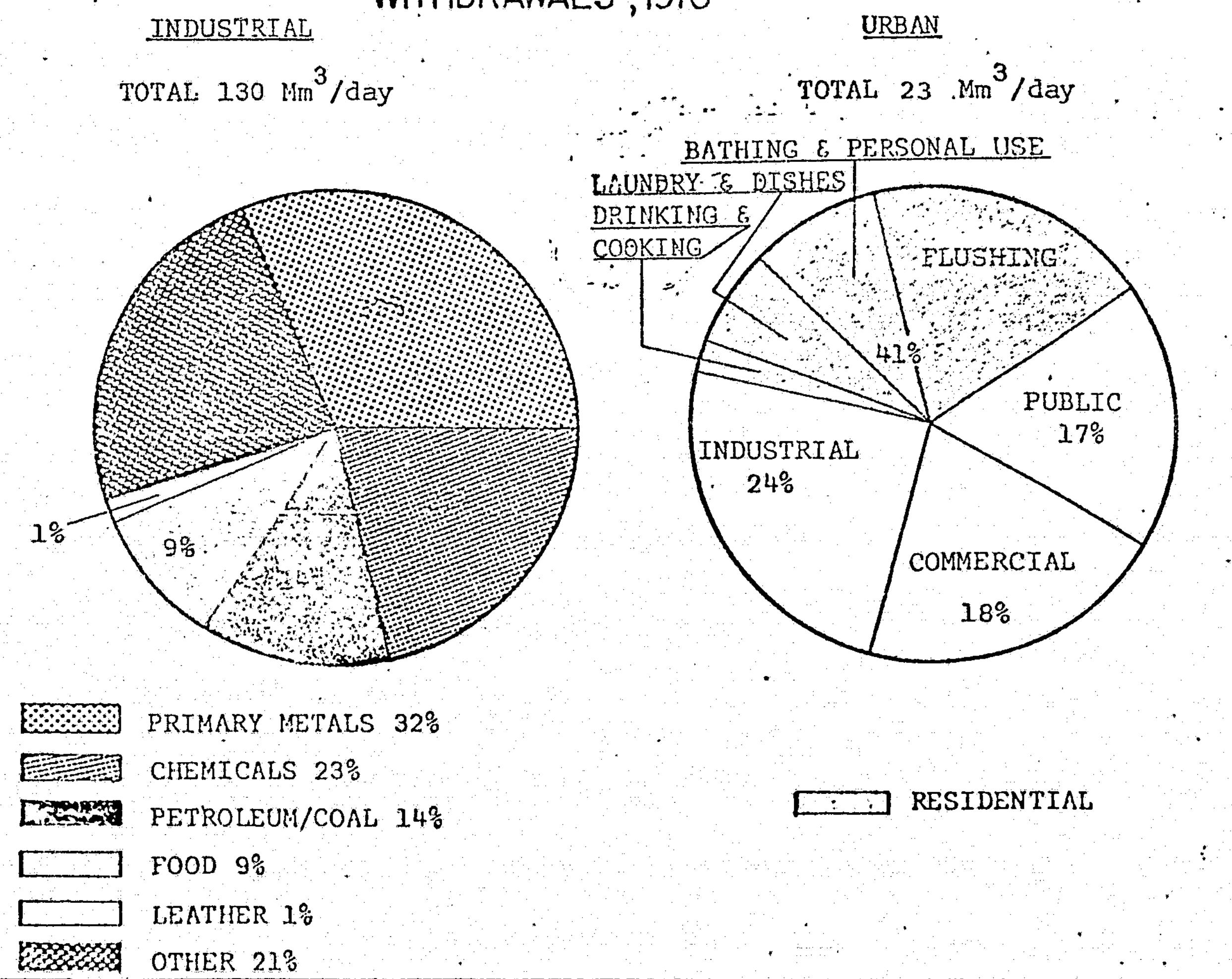


DISPOSAL OF IRRIGATION WATER IN PERCENT OF THE TOTAL WITHDRAWAL

FIGURE 11

FIGURE 12

WITHDRAWALS, 1970



Industrial manufacturing and urban use

The use of water by industry presents a different picture. The two major users are: 1) the manufacturing industry; 2) the electrical energy industry.

The manufacturing industry is popularly thought to be a significant user of water, because the quantities of water required to produce a unit quantity of most industrially manufactured products are large. In reality, the manufacturing industry's water usage is modest compared to the total industrial demand (approximately 23%). The reason is that the manufacturing industry employs considerable levels of recirculation. Recirculation will further increase in the future, because it is generally cheaper than the acquisition of "new" water. Because the manufacturing industry lends itself to concentrated application of water-conservation practices, industrial water use can and will be maintained within bounds. The electrical energy industry is the major user of industrial water: it will be discussed later, because of its spectral requirements for remote sensing. Municipal water represents a relatively small fraction of U.S. withdrawals: it is characterized, however, by *high consumption* and the highest prices.

These two usages, whose highlights are sketched in Figure 13, are not in and by themselves directly amenable to Remote Sensing: they are, however, strongly influenced by the two applications which follow: they are thus *indirectly amenable to the application of remote sensing.*

The siting, sizing and design of reservoirs

The provision of reliable water supply requires reservoiring. This is because the occurrence of precipitation differs significantly from the

rate of demand. The role of reservoirs is to smooth the temporal discrepancies between demand and supply.

As shown in Figure 13, the U.S. reservoir capacity implemented thus far is but a fraction of the total which is effectively utilizable. However, most of the *better* U.S. reservoir sites have already been exploited. This means that additional capacity must be paid for at higher prices than those already paid for the "best" sites.

As shown in Figure 14 the marginal cost of reservoir development, and consequently of flow augmentation, varies by two orders of magnitude among U.S. regions. A convenient means to normalize waterworks development costs between regions is in terms of the costs required to satisfy a common percentage increase in the demand. Figure 15 indicates the marginal costs, by region, required to increase the 98% reliable flow by 1%. Figure 16 shows the parameters which enter the cost for a typical median subregion.

Reservoir siting for maximum cost-effectiveness is thus of major importance to the field of water resources. In the conventional reservoir siting procedure, presented schematically in Figure 17, several promising candidate sites are initially selected, based upon topographic and geographic characteristics. Each site displays characteristic relationships between capacity, inundated area and water height, which are functions of the topography. Similarly, the cost of damming is influenced by topography and the site's geology. Evaporation and leakage losses are influenced by geography, climate, topography and soil characteristics.

FIGURE 13

EXISTING VERSUS MAXIMUM IMPLEMENTABLE RESERVOIR CAPACITY

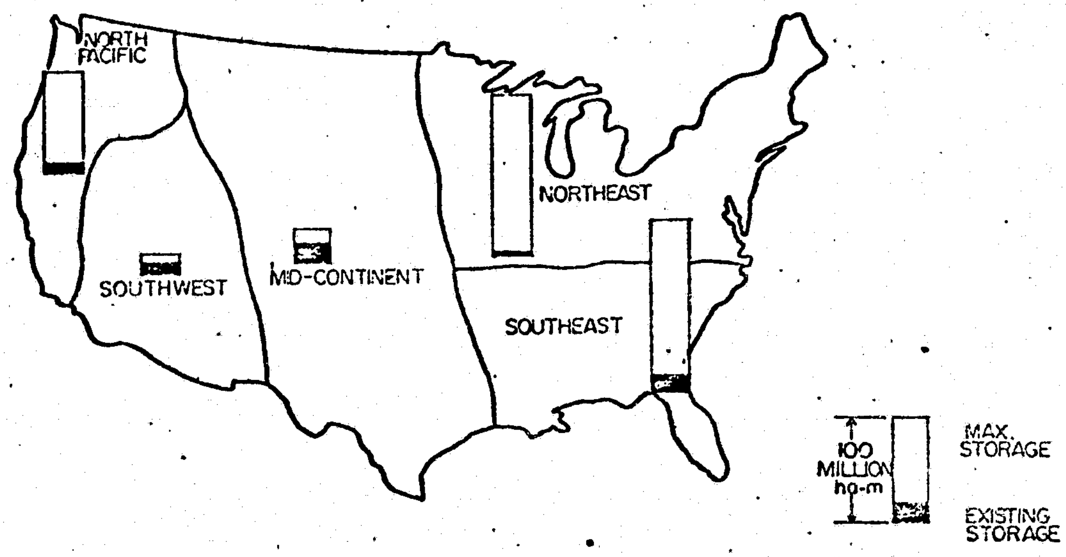


FIGURE 14

RANGE OF MARGINAL STORAGE/FLOW COSTS TO PROVIDE INCREASE IN MARGINAL RESERVOIR STORAGE IN THE U.S.

98% AVAILABILITY

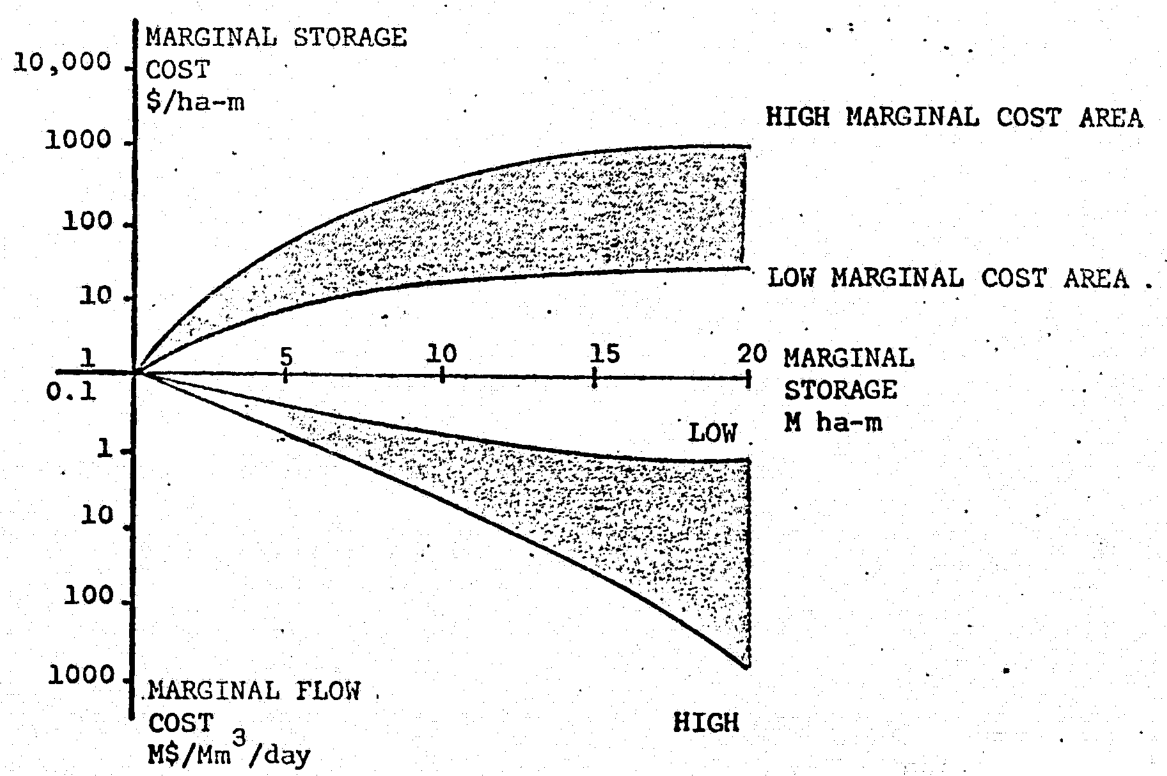


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FIGURE 15

RESERVOIR DEVELOPMENT COST TO ACHIEVE 1% FLOW INCREASE

(98% RELIABLE FLOW)

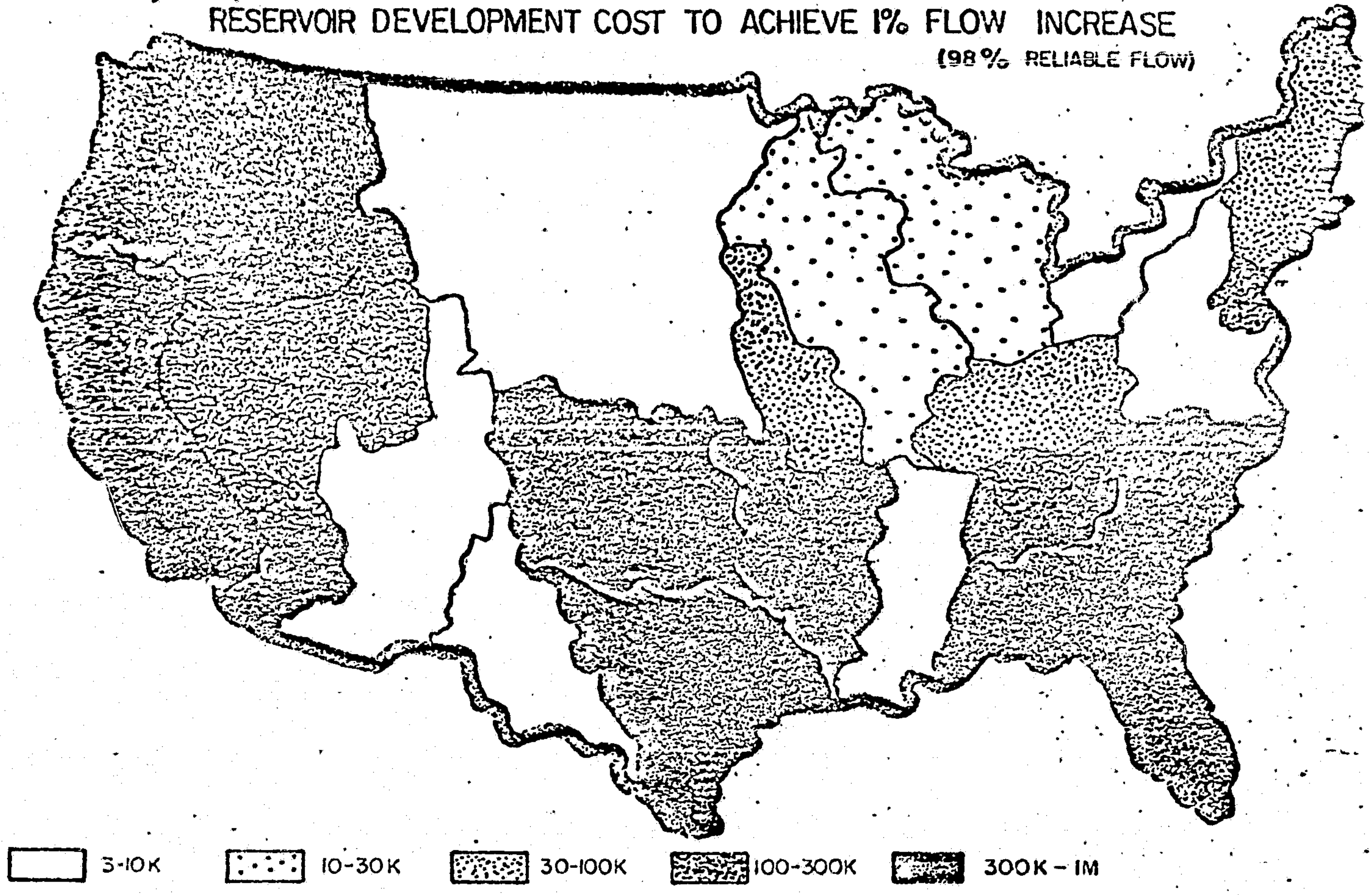
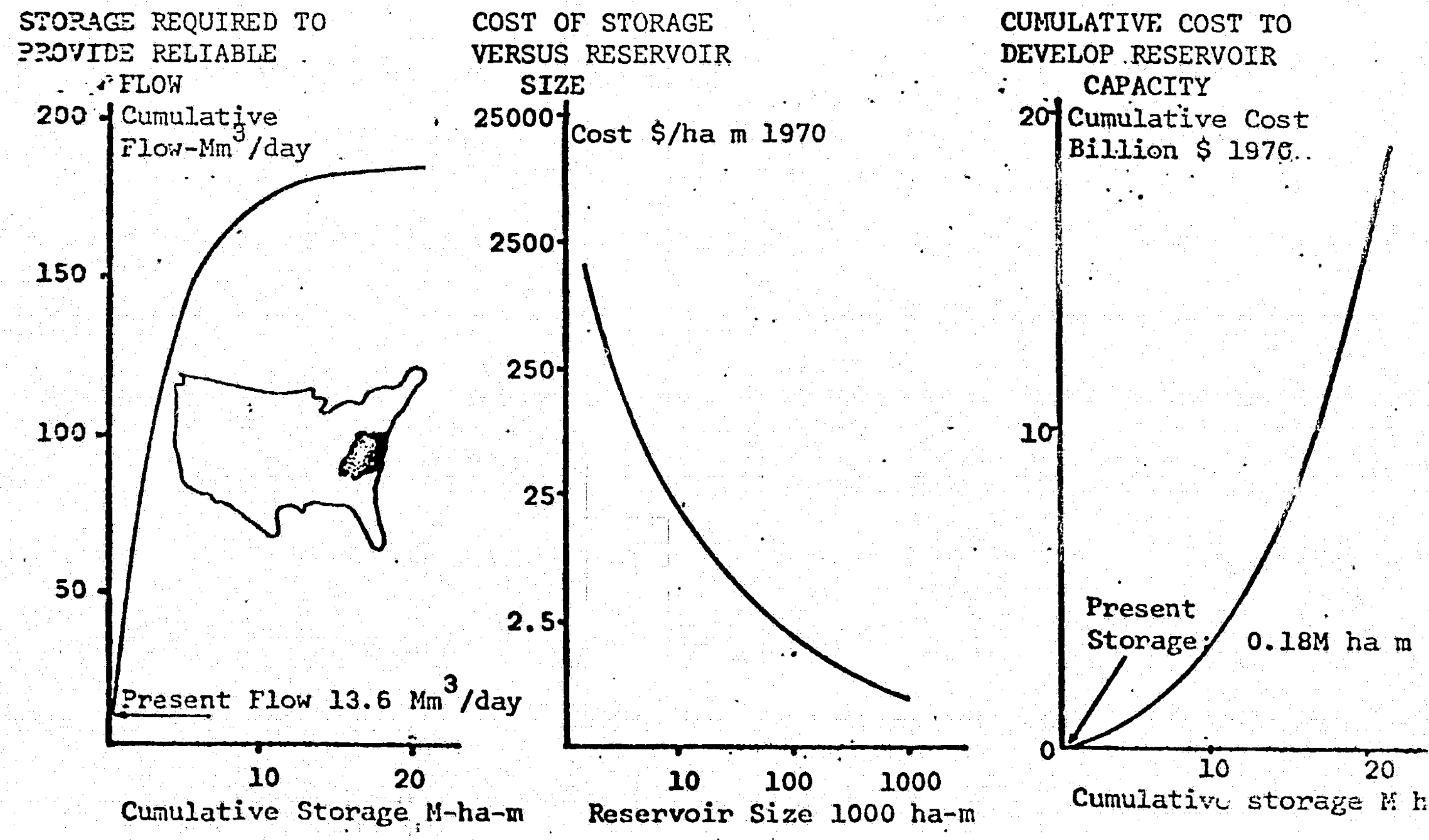


FIGURE 16

TYPICAL PARAMETERS FOR A MEDIAN WATER SUBREGION (CHESAPEAKE)



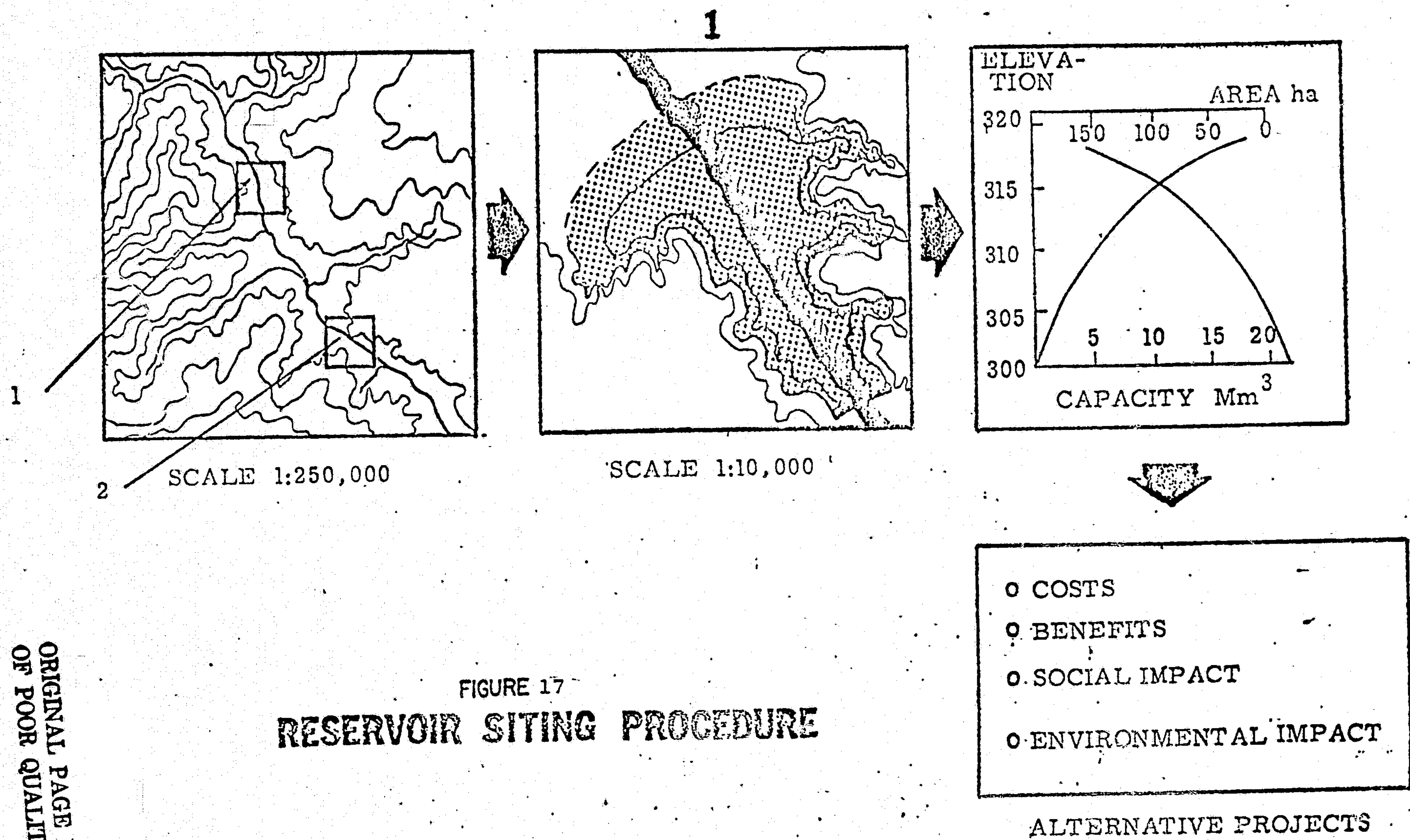


FIGURE 17

RESERVOIR SITING PROCEDURE

The selection of candidate reservoir sites requires availability of topography on regional scales - 1:1,000,000 to 1:250,000 - and on local scales - 1:50,000 to 1:10,000. Local scales are obtainable from aircraft-borne stereoimagery. Topographic maps at regional scales could be obtained from stereo satellite imagery - not yet routinely available from NASA systems.

The assessment of the environmental, economic and social impact of contemplated new reservoirs is a major statutory requirement. Their principal components are indicated in Figure 18. Several elements of these *are amenable to current-capability remote sensing.*

Hydrologic Modeling

The presence of reservoirs does not automatically insure adequate water management. By this is meant matching the supply, which derives from highly variable precipitation, to the demand, also variable, but with a different rhythm, without wastes or shortages of water. This match is attempted by means of hydrologic models: these are mathematical formulations which strive to represent the "watershed transfer function," i.e. the relationship between input precipitation and output streamflow or accumulation of water in reservoirs.

The purposes of modeling are threefold:

1) Predict *in real time* the outflow corresponding to precipitation events. The purpose is normal management or flood alleviation, if the outflow is too great.
2) Compute the outflow corresponding to unusual high-intensity events: for example, the so-called 50 or 100-year rain.

FIGURE 18

PRINCIPAL ECONOMIC, SOCIAL, AND ENVIRONMENTAL FACTORS IN WATER REGULATION PROJECTS

PROJECT ECONOMICS

BENEFITS

- Water Supply Value
- Recreation Value
- Power Revenue
- Flood Damage Reduction
- Navigation Value

COST

- Land Loss
- Flow Loss
- Relocation of Population Structures
- Relocation of Public Facilities Services
- Alteration of Taxation Base

SOCIAL IMPACT

- Impact of Influx of Federal State Money
- Impact on Overland Transportation
- Altered Recreation Pattern
- Impact on Historical/ Archeological Factors
- Loss of Goodwill of Relocated Industries
- Alteration of Community Regional Growth Cohesion
- Alteration of Scenic Esthetic Value
- Impact on Employment Base

ENVIRONMENTAL IMPACT

- Fish/ Wildlife
- Air
- Water
- Noise
- Forest/ Plant Life Ecology
- Altered Downstream Revenue/ Environment

The purpose is the proper sizing of waterworks (dams, levees, retainers, culverts, bridges....): not too small so as to allow the excess water to do damage, not too large so as too cost too much.

3) Simulate the changes to the hydrologic regime of a watershed consequent to modification of its land use (for example, deforestations, reforestations, urban and suburban developments..).

Corresponding to these three objectives, three types of models exist:

Management models

Planning models

Simulation models

Some modern models combine all three functions. Advanced models require the following inputs:

Precipitation - from conventional gages or *DCP's*

Snowmelt - from conventional snowgages or *measure of snow area from LANDSAT plus DCP's* to gage snow depth

Surface characteristics of watershed: slopes, friction - from aerophotography *or LANDSAT remote sensing*

Stream patterns - *same as above*

Water Impoundments - *same as above*

Streamflow - from conventional gages or through *DCP's*

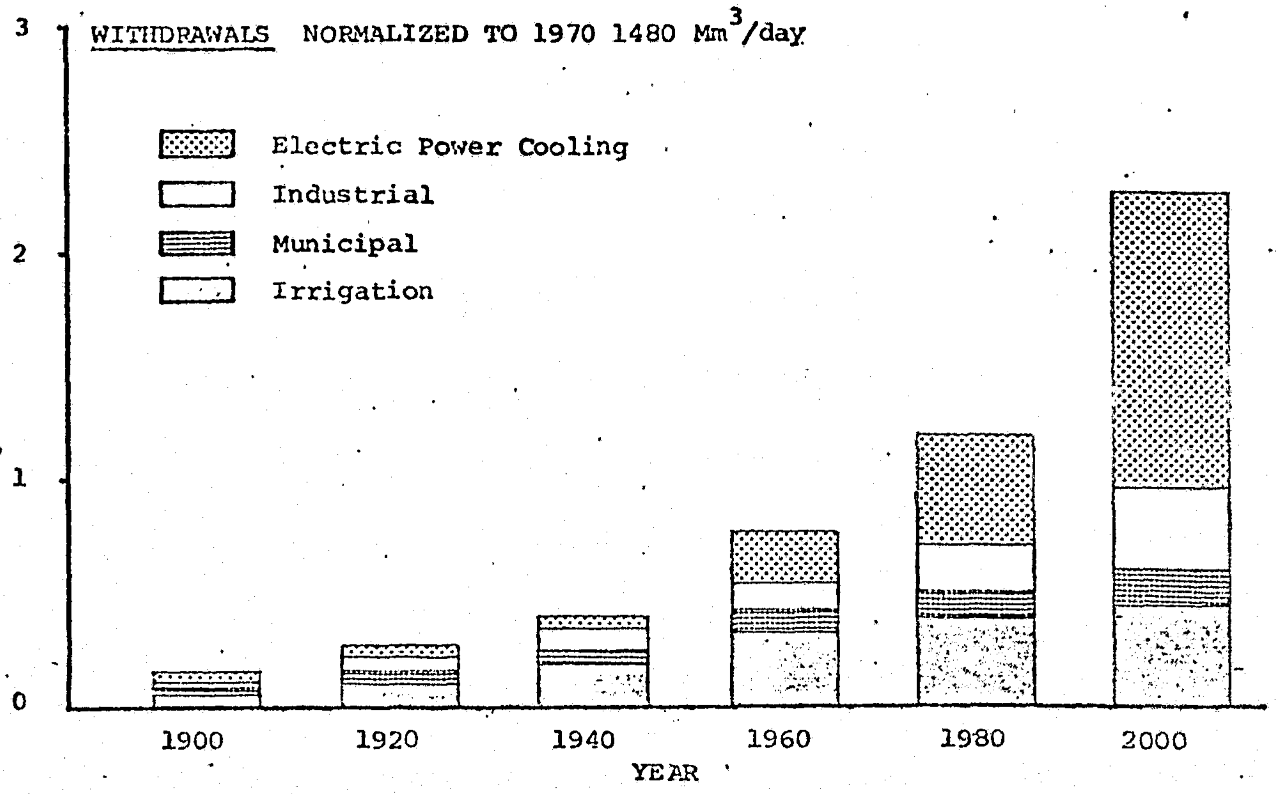
Subsurface characteristics : infiltration, soil moisture, depth of permeable layers - from conventional records or DCP's. In the future, possibly by active and/or passive microwave remote sensing.

Industrial Cooling

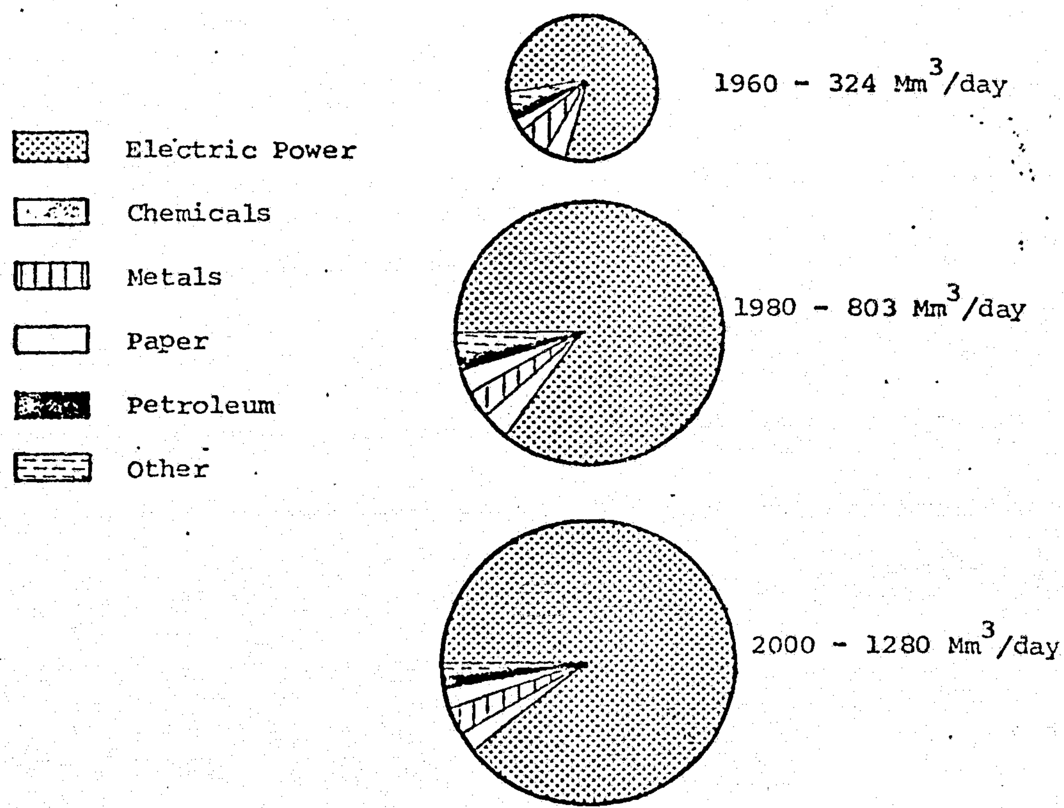
As indicated before, a significant fraction of industrial water usage is devoted to cooling industrial processes, with an ever-increasing use predicted. As shown in Figure 19,

FIGURE 19

GROWTH OF U.S. WATER DEMAND



GROWTH OF INDUSTRIAL COOLING IN THE U.S.



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the overwhelmingly primary user of cooling water is the electrical energy-generating industry.

Cooling is needed regardless of the primary fuel employed. In the case of nuclear fuel the efficiency is somewhat less than for fossil fuel: thus approximately 20% more cooling water per kilowatt hour generated is required in nuclear installations with respect to fossil fuel fired plants. If the cooling requirements are expressed in conventional thermal units, very large numbers ensue, meaningless to most persons.

A compact and visible way to express the cooling requirements is to describe them in terms of "Boiling Potomacs." This is the heat quantity required to bring the River Potomac (flow of 1 billion gals/day) from normal temperature (20°C) to the boiling point (100°C).

By way of comparison, note that the present total U.S. 98% regulated flow is sufficient to cool 375 Boiling Potomacs.

Dumping of heated water is severely restricted by law.

The reason is its estimated effect on aquatic life. Fish thrive best within a limited temperature range. A prolonged temperature rise much above the range of each species will cause death. The problem is not so much the killing of adult fish, since they can escape towards cooler waters; rather, the fact that temperatures still well within the adult's tolerance are lethal to larvae, thus threatening extinction of the species within the warmed waters.

The other problem is that higher temperatures favor growth of aquatic plants, which comsume oxygen, thus imposing additional environmental stress upon fish.

By contrast, higher temperatures favor bacterial action, which aids the digestion of pollutants.

Although evidence for widespread damage and deleterious modifications in the ecological balance from heated waters is not conclusive, Federal law now restricts the temperature differential between heated effluent and river to $5^{\circ}C$ in Summer, $10^{\circ}C$ in Winter, and limits maximum outlet temperature to $32^{\circ}C$.

These restrictions vastly increase the required cooling water flow.

For example, the 10° Winter temperature restriction increases the required cooling flow 8 times over and above the flow which would be needed if heated water could be dumped at boiling temperature. The $5^{\circ}C$ Summer restriction causes a sixteen-fold flow increase. As the $32^{\circ}C$ upper limit of the temperature of the receiving water is approached, flow requirements increase even further.

A feel for the magnitudes involved can be obtained by looking at the practical situation forecasted for the River Potomac by the Potomac Electric Company for construction of a fossil-fuel fired electric generating plant.

The 99% reliable flow of the Potomac specified by PEPCO to cool this plant would support an electrical generation of no more than 2.6 billion kilowatt-hours per year: this approximately equals 6 ten-thousandths of the expected U.S. electrical energy demand in 1985.

Since total U.S. river flow is equivalent to 375 Potomacs, all U.S. inland flow could support approximately only 22% of the 1985 U.S. electrical energy demand, if each river were used once. In practice, some of the larger watercourses could support more than one plant, located serially along the river: on the other hand, much of the 375 Potomac-equivalent inland flow resides in small rivers, too small to support economically practical power plants of any size.

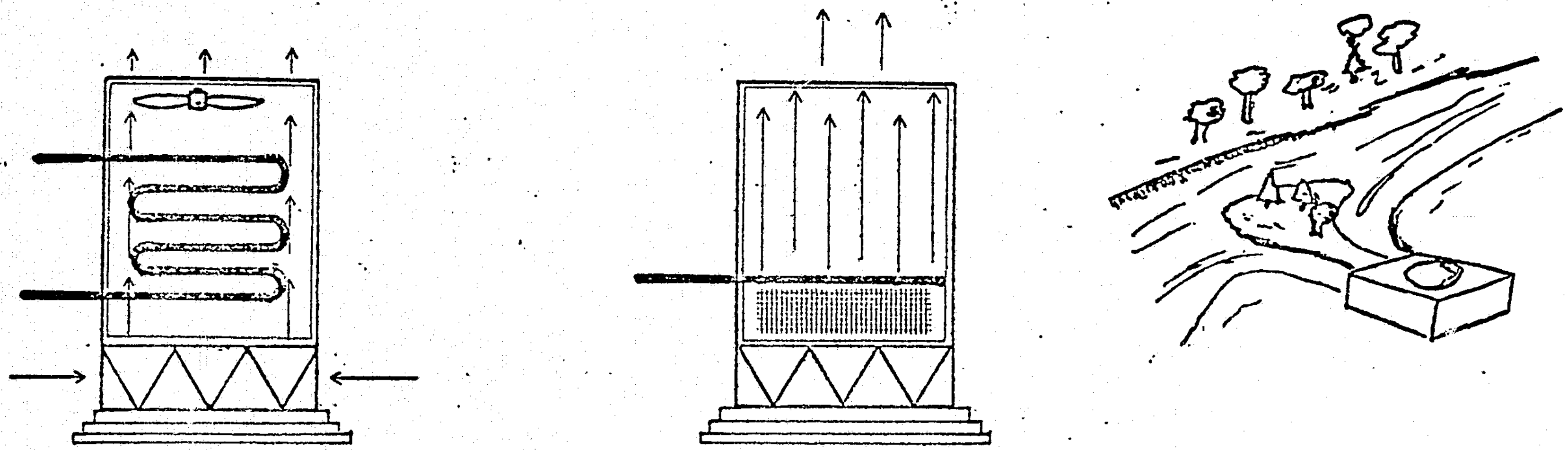
Current technology offers three basic cooling techniques. These, together with the corresponding cost data, are depicted in Figure 20.

The cleanest environmentally is the Closed Cycle technique, wherein waste heat is transferred to the atmosphere. It is also the most expensive. The most economical technique, if sufficient flow is available, is the Flow Cooling Technique discussed previously. In between these two extremes lies the Evaporative Cooling Technique, which utilizes the water's heat of vaporization (600 Cal/Kg). Its problem is the large amount of steam generated and released to the atmosphere: approximately 100 m^3 (25,000 gallons) per minute of water equivalent per 1,000 megawatt electric output. If all U.S. plants were to operate with this technique by 2000 AD, the equivalent of 29 Potomacs (116 million m^3/day) would be turned into steam continuously. This may not cause macro-

FIGURE 20

COSTS OF COOLING TECHNOLOGIES

IN 1970 DOLLARS, FOR FORECASTED U.S. INVENTORY TO YEAR 2000



CLOSED CYCLE	EVAPORATIVE	FLOW
CAPITAL COSTS ($ BILLION 1975)		
68	17	6.2
YEARLY RECURRING COSTS ($ BILLION 1975)		
5.4	2.7	0.5

scale climate changes, but is probably sufficient to impact local microclimates.

For these reasons, the exploitation of estuarine and bay waters for electric energy generation cooling has already been initiated and is expected to grow in the future. Utilization of estuarine and tidal flow is crucial to meet the forecasted U.S. electrical energy demands of the future.

Eight estuaries like the Chesapeake Bay, completely tapped, could provide a cooling flow equivalent to that of all U.S. rivers.

Optimal exploitation of estuarine and bay tidal flow requires detailed knowledge of the statistics of circulation and diffusion of the water mass in estuaries and bays as shown schematically in Figure 21. Determination of these statistics is lengthy and costly by conventional surface methods: this is the principal reason why they are as yet insufficiently known. Particularly worthy of consideration in this respect are the pressures exerted by conservationist groups who oppose and delay new plant construction: these require that the environmental impact be computed with a high degree of precision and credibility.

This task is eminently amenable to application of remote sensing techniques.

Pollution Dilution

A major potential requirement for water is dilution to reduce water pollution. The cost of wastewater treatment increases with the degree

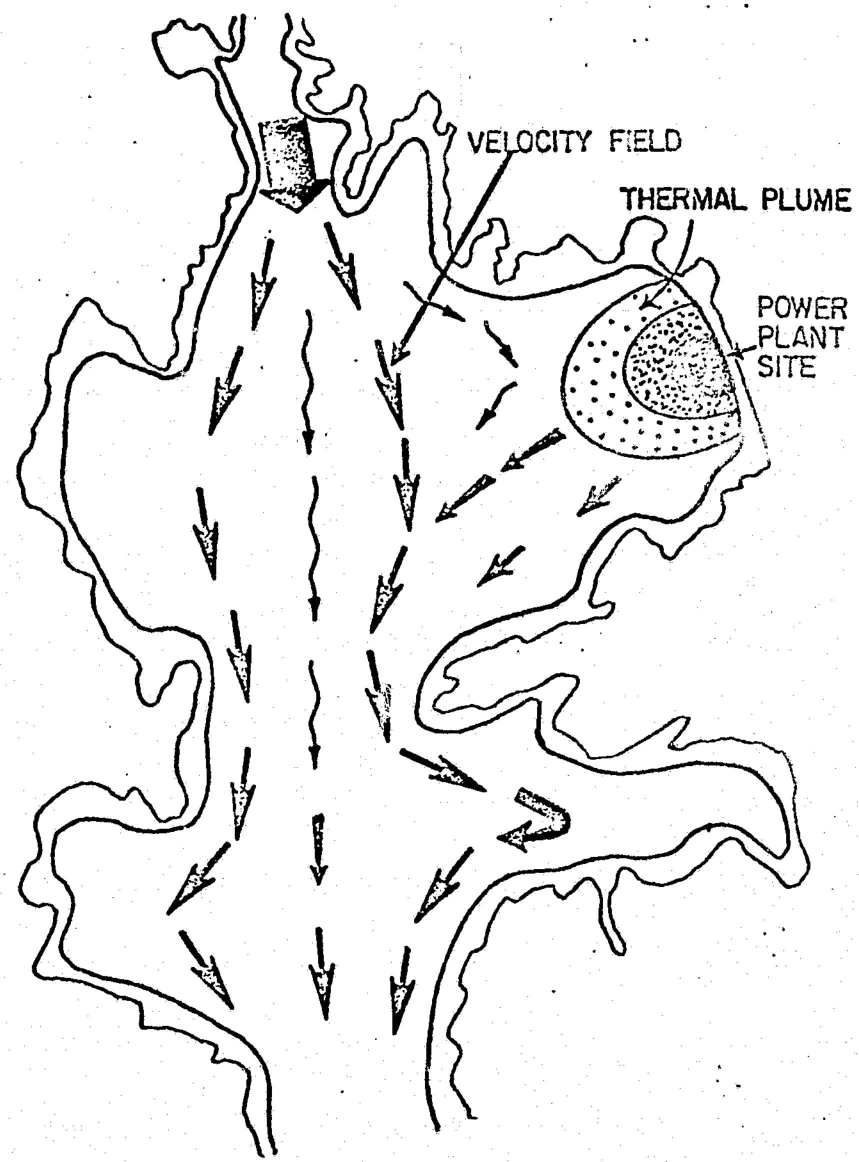


FIGURE 21

TYPICAL ESTUARY CIRCULATION/DIFFUSION PATTERN

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of treatment, as shown in Figure 22. "Percent treatment level" is defined as the percentage reduction in biological oxygen demand (BOD) achieved within the effluent. For example, U.S. urban sewers possess a typical ultimate BOD of 500 mg/liter; 90% treatment would reduce this to 50 mg/liter at a cost of approximately $5/person/day.

An effect equivalent to treatment can be obtained by massive dilution. For example, if the sewer effluent with a BOD of 500 is diluted 10 times, an equivalent BOD of 50 mg/liter will result: the same as for a 90% treatment plant. Tolerable pollution levels are of order of 5 mg/liter; in this example, to achieve these, a dilution ratio of 100:1 is required.

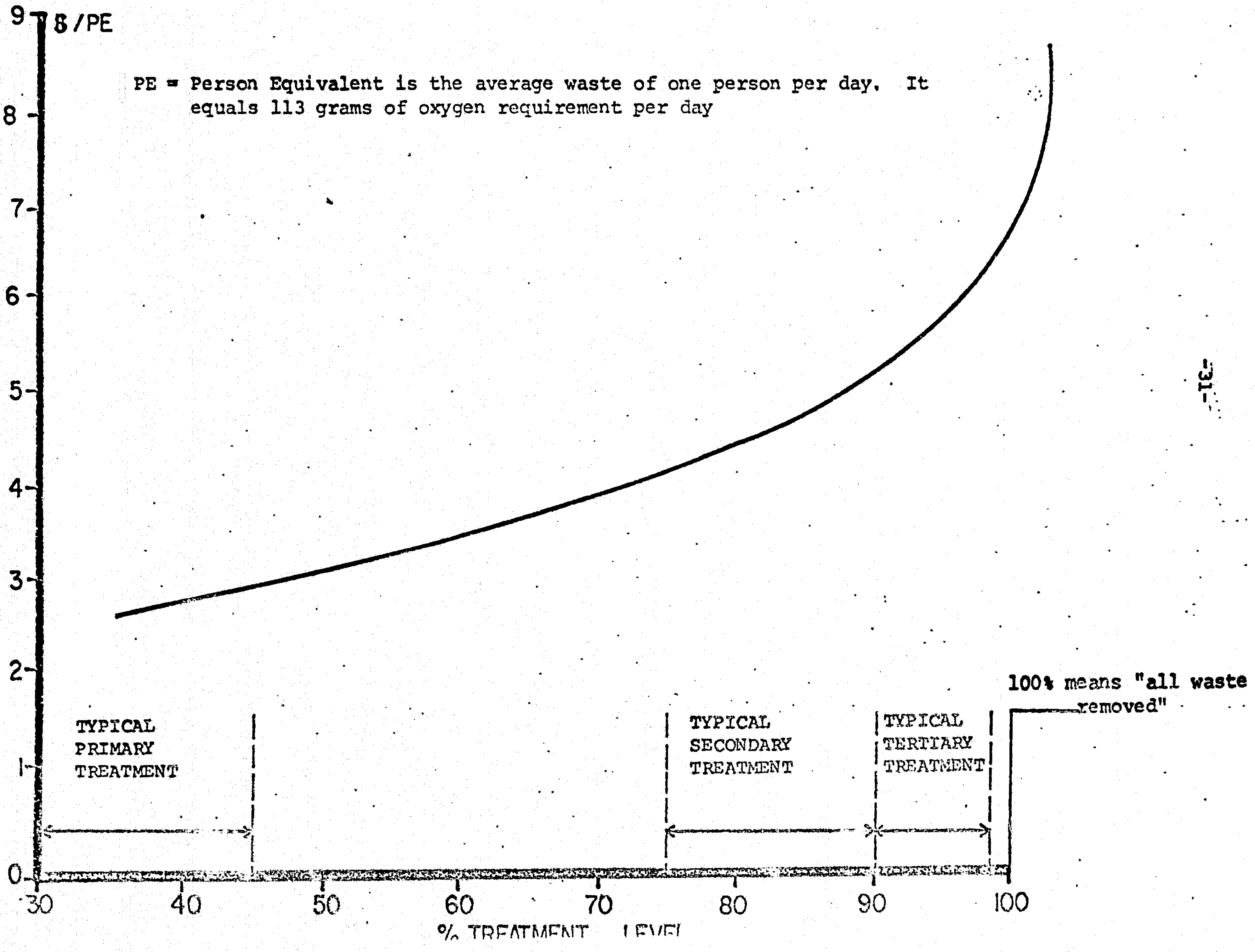
To dilute 1 PE = 113 grams of oxygen per day, to a tolerable level of 5 mg/liter per day, requires a diluting amount of water equal to $\frac{113,000}{5}$, or 22.6 m^3 (5,700 gallons per person per day).

Choice of the optimum mix between treatment and dilution is economically very important due to the large and ever-increasing PE effluent level of the U.S, as a whole.

One extreme of the mix is the "all treatment" approach. The other is the "all dilution" approach. The "all dilution" approach would require quadrupling the existing reservoir capacity. Neither extreme is optimal; there is an in-between mix which possesses the lowest cost. A barely tolerable DO level of 4 mg/liter in most U.S. watercourses would call for a 20% increase in reservoir development by AD 2000.

FIGURE 22

THE COST OF TREATMENT OF HOUSEHOLD WASTE



To achieve higher Dissolved Oxygen (DO) levels, and thus cleaner watercourses, the flow requirements and corresponding reservoir development levels and costs increase drastically.

A key economic "driver" within this approach is reservoir development, already mentioned, coupled with improved management from more perfect hydrologic models.

Another approach is analogous to the one pointed out for the electrical-energy cooling situation: the use of bays and estuaries. This is justified by realizing that bays and estuaries act as natural concentrators of the world's waterborne wastes. For example, ten of the world's most industrial and densely populated areas are built around bays and estuaries: New York, London, Tokyo, Buenos Aires, Shanghai, Calcutta, Osaka, Bombay, Los Angeles, Philadelphia. These areas alone support the household and industrial wastes of some 100 million people.

The problem is to know the circulation and diffusion pattern of the estuary. The solution is the placement of the pollutant outlet at such a point where the net statistical effect of the currents will carry the polluting material away from the shore, or into zones where pollution is tolerable. The solution involves operations upon one or more of three variables: placement of the effluent outlets; average degree of treatment of the effluents; and temporal modulation of the amount of effluent and its degree of treatment.

Summary

In most of the applications of Water Resources, the exploitation of remotely sensed products requires the intermediary of models, i.e. mathematical or empirical formulations which allow the correlation of "what is seen" with "what happens." The principle of watershed transfer modeling was explained above: other models operate similarly, although on different mechanisms, and with different formulations and coefficients.

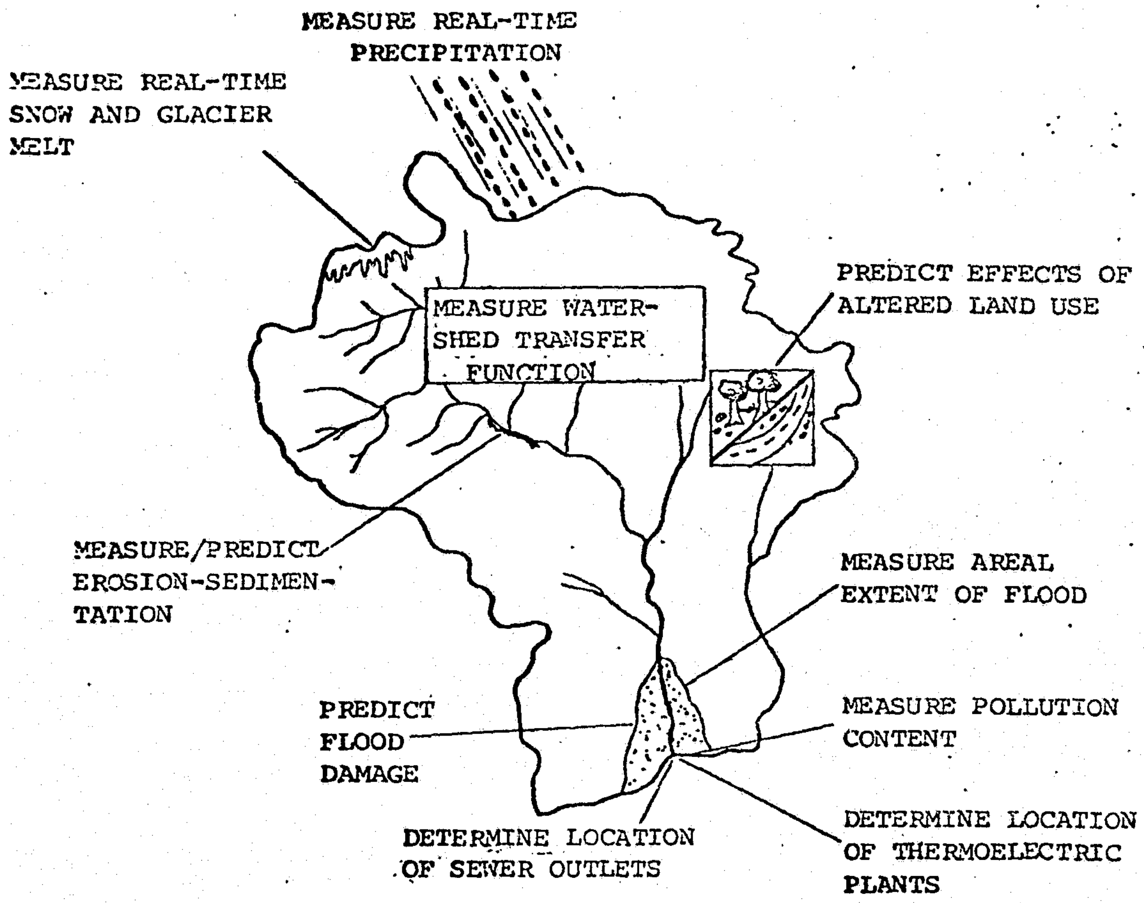
Figure 23 recapitulates the applications in visual forms: in the upper portion, by functions; in the lower, by the specific type of modeling currently in existence or under development. Note for example that the function "Measure Real-Time Precipitation" has no corresponding model: this is because the state of the art of correlating visible phenomena, e.g. cloud shape, type, etc. with precipitation is as yet in its infancy.

These applications of remotely sensed data are summarized in tabular form in Table 1.

FIGURE 23

NEAR TERM APPLICATIONS OF REMOTE SENSING

BY FUNCTION



BY TECHNIQUE

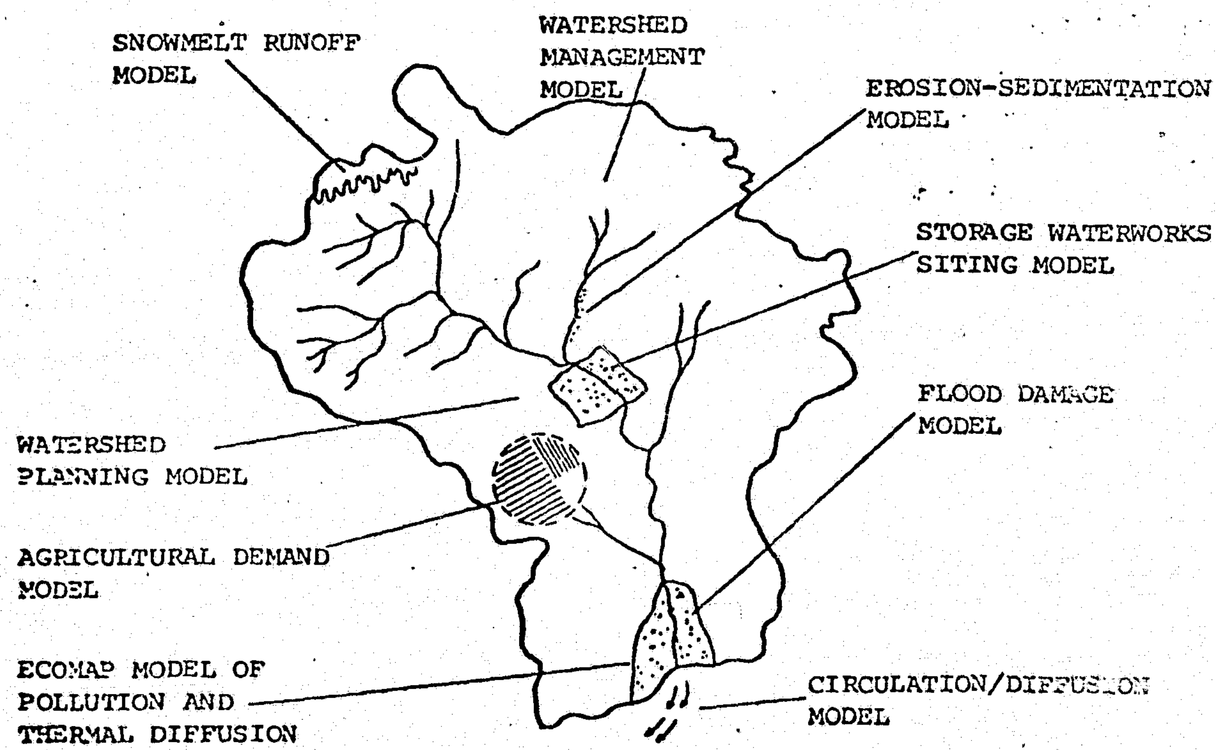


TABLE 1

PRINCIPAL ADDRESSABLE FUNCTIONS IN WATER RESOURCES
Liquid Precipitation Measurement
As input to hydrologic models
Watershed Surface Mapping
for hydrologic modeling
Inundation Mapping
for flood plain delineation
Turbidity Spotting
as a pollution indicator
Wetlands Mapping
institutional, reclamation, management
Snow Depth Mapping
for melt estimation
Snow Area Mapping
for melt estimation
Irrigated Area Mensuration
as indicator of water demand
Bay and Ocean Current Circulation and Diffusion
to design pollutant effluxes
Soil Moisture Mapping
for estimation of irrigation demand
Storage Waterworks Siting
to optimize reservoir cost/benefit

2 CURRENT AND PROJECTED FUTURE USER REQUIREMENTS FOR REMOTE SENSING OF WATER RESOURCES

Water resources activities are ultimately aimed at action: either by control of deleterious effects of water, or by the construction of waterworks to provide and manage the supply of water to meet the demands. These action-oriented activities are supported by two types of informational activities:

1. Collection of data - primarily statutory, some real-time.

2. Transformation of data into information for the generation of action plans and tradeoffs. These are generally accomplished through the intermediary of mathematical or empirical formulations known under the general category of "modeling."

Table 2 presents a panorama of current activities by these two categories: it includes, in italics, additional activities desired by the users, currently under research but not yet in widespread operational use: their fulfillment by remotely sensed means is also in the future. The Table designates the methods in current usage, and the activities amenable to satellite-based remote sensing technology. Also listed for completeness are those activities amenable to being serviced by the technology of spaceborne relay transmission (DCS).

It can be seen that the role of remote sensing in fulfilling these activities boils down to two functions:

1. Relay of data via DCP's

2. Mapping

TABLE 2

CATEGORIES OF WATER RESOURCES ACTIVITIES

	CURRENT METHODS	ADVANCED METHODS
Collection of data		
Precipitation, rain	Raingages	DCS relay
Precipitation, snow	Snowgages	DCS relay
Water equivalency of snow	Snow depth & weight gages	DCS relay
Streamflow	Streamflow gages	DCS relay
Groundwater level	Depth gages	DCS relay
Water Quality	Water quality gages	DCS relay
Mapping of waterbodies	Aerophotography	SRS
Soil Moisture	Manual Sampling	DCS relay, SRS
Snowmelt propensity	Aerophotography	SRS
Generation of Information		
Watershed transfer functions (hydrologic modeling)	Aerophotography, Soil Surveys	SRS Soil Surveys
Snowmelt forecasts	Aerial mapping of snowfields	SRS
Flood mapping	Ground surveys, aerophotography	SRS
Circulation and diffusion of currents	Buoys, aerophotography	SRS plus hovering platforms, DCP
Wetland delineation and content	Ground Surveys, aerophotography	SRS
Water Pollution Pattern	Buoys, boat surveys	SRS plus DCP
Cloud-precipitation correlation	Weather radar	SRS + models
Irrigated patterns	Ground Surveys	SRS
Evapotranspiration measurements	Ground measurements (Pans)	SRS - insolation, weather

SRS - Satellite-based Remote Sensing

DCP - Digital Communications System

The latter, with reference only to the near-term applications - i.e. those not in Italics in Table 2 and estimated to reach fruition before 1985 can be further subdivided into:

a. Inventory mapping, i.e. the subdivision of watersheds into portions with differing characteristics, and measuring their total area, but without assigning their geographic location. This is currently sufficient to satisfy approximately 80% of the current user models of watershed transfer functions, plus a large portion of users interested in identifying water pollution, plus most of the snowmelt forecast users.

b. Land use mapping, i.e. the subdivision of areas into portions of different characteristics, including the assignment of their geographic location and boundaries, plus measurement of the respective areas. This mode is required by:

   o 20% of the users engaged in hydrologic modeling, notably the SCS.

   o 20% of the users engaged in snowmelt forecasting

   o Flood mapping users

   o Users engaged in wetland delineation

   The evolving sophistication of the modeling techniques will tend in time to progressively favor land use mapping over the simpler inventory mapping.

c. Dynamic mapping, i.e. the measurement of the statistical changes of certain characteristics. This mode is required by users engaged in measuring the circulation and diffusion of currents, and with assessing the migration of water pollutants.

The more advanced functions, shown in Italics in Table 2 , require:

Soil moisture - both Inventory and Land Use mapping, depending upon the application

Snowmelt propensity - Inventory

Cloud - precipitation correlation - Both

Irrigation patterns - both

Evapotranspiration measurements - inventory.

In summary, the future use of imaging remote sensing in water resources differs from that in Agriculture by:

1. The requirement to map rather than to inventory
2. Thus, the need for complete coverage of the area of interest rather than just of sample segments.

This does not mean that every user will need the full format of LANDSAT imagery.

Table 3 depicts the domains, in terms of geographic surface, of the users in the three categories:

1) Local users - Generally Counties
2) Small Users - States and State-wide extension services of the Federal Government
3) Large Users - Federal Agencies whose roles transcend the capabilities and/or interests of the State and local users.

With reference to Table 3, the minimum surface of homogeneous area denotes the smallest area which the user wishes to be identified within his watershed as being characterized by distinct properties.

TABLE 3

AREAS OF WATERSHEDS CONTROLLED BY USERS, HECTARES

USER CATEGORY	EXAMPLE	WATERSHED AREA			MINIMUM SURFACE OF HOMOGENOUS AREA			APPLICATION
		MIN	MED	MAX	MIN	MED	MAX	
Local	= Counties = SCS Extension Service	1	50	150	0.5	10	30	Waterworks Design Erosion Stabilization
Small	= States = SCS Regional extension Service = ARS Test watersheds = USGS extension Service	100	10,000	300,000	20	2,000	10,000	Small Reservoir Design Drainage Works Design Waterworks Design Environmental Impact of Land Use charges Reservoir Management
Large	= Corps of Engineers = USGS	50,000			7,000			Siting/Location of Major Reservoirs Channelization waterworks for Water Supply Environmental Impact of Land Use Charges

In other words, it represents the smallest distinct fraction of his watershed.

Table 4 presents the current accuracies with which users perform their appointed hydrologic functions.

The following conclusions emerge:

1. The accuracy requirements for discrimination and area measurement are in principle equivalent to those of agriculture for, although the accuracies presented in Table 4 appear more relaxed than those applicable to agriculture, they refer to the more stringent Land Use mode. Also, whereas the agricultural user is basically only interested in accurate measurements of small areas (segments), the water resources user requires mapping of his entire watershed.

2. Achievement of area mensuration accuracy is, however, easier in water resources, due to the fact that the areas of interest are of greater extent than most agricultural fields. Figure 25 depicts the errors versus area achievable as a function of resolution, on the reasonable assumption of 95% discrimination accuracy (not yet achieved consistently, but necessary to meet the requirements). It can be seen that all LANDSATS up to D miss the local users, but can substantially satisfy the small and of course the large users.

TABLE 4

CURRENT HYDROLOGIC USER PERFORMANCE

MEASUREMENT	ACCURACY
ELEVATION	SEE FIGURE 24
SMALLEST AREA FRACTION	90% - 95%
DISCRIMINATION/IDENTIFICATION OF AREA CONTENT	95%
STREAMWIDTH (FOR WATERSHED MODELING)	0.1 - 0.25 METERS FOR SMALL USERS 1 TO 3 METERS FOR LARGE USERS
STREAMLENGTH (FOR WATERSHED MODELING)	∿500 METERS FROM ISSUANCE FOR SMALL, $\gtrsim$1000 METERS FOR LARGE USERS.
SNOW AREA	∿90%
FLOODED AREA (TRAVERSE)	±5 METERS UP TO 100 METERS ±100 METERS ABOVE 1,000 METERS
WETLAND AREA DELINEATION	95% - 97%
WATER POLLUTION CONTENT	∿90 - 95%
WATER POLLUTION PATTERN	NO SPEC.

FIGURE 24

USER REQUIREMENTS FOR ACCURACY OF CONTOUR HEIGHT MEASUREMENT

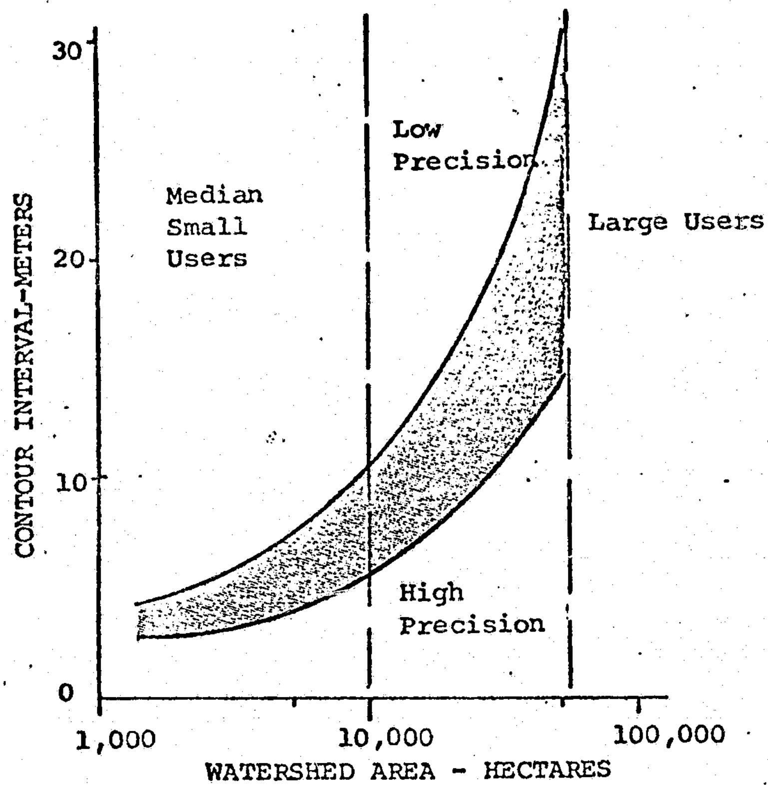
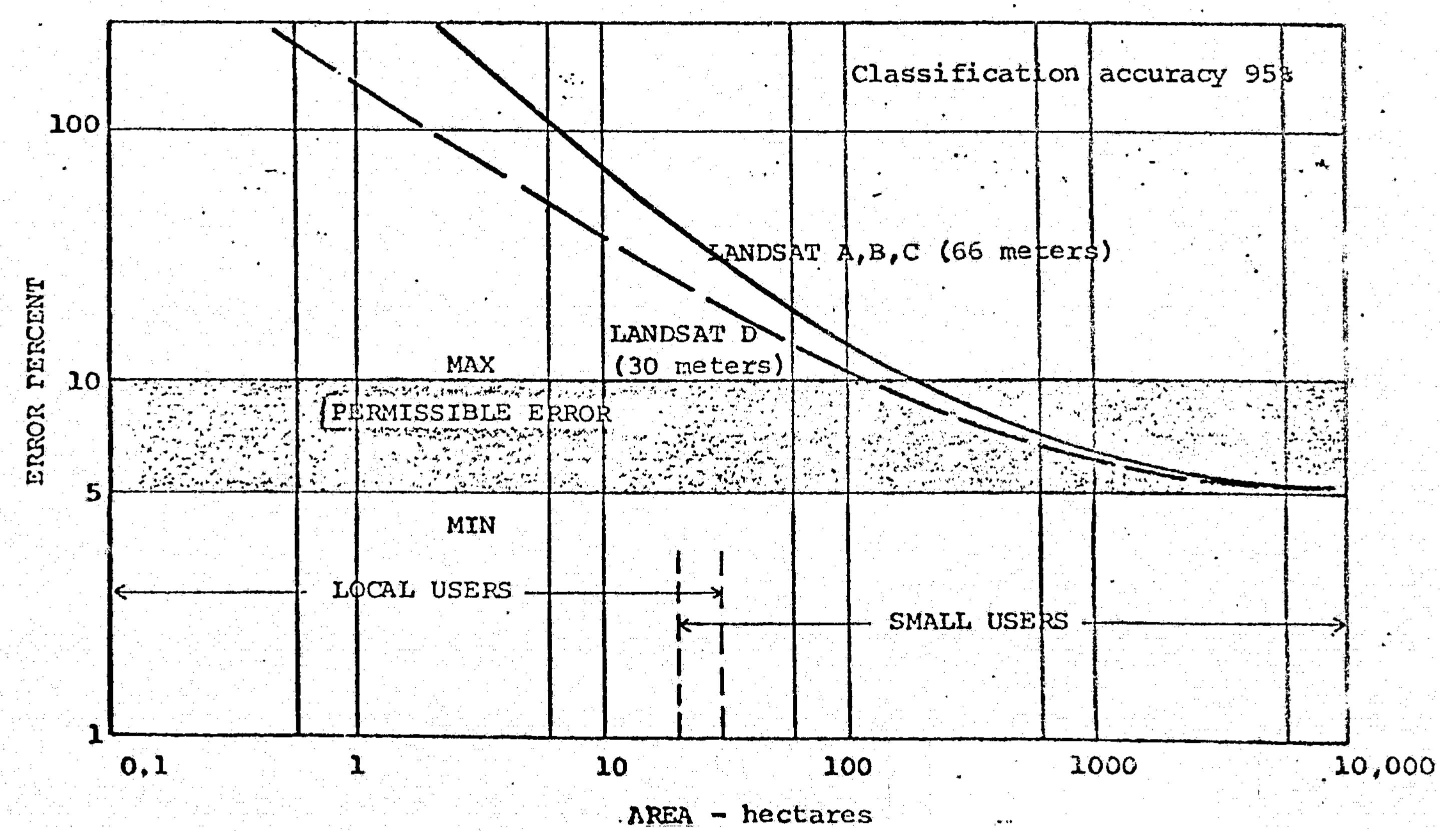


FIGURE 25

AREA MENSURATION ACCURACIES VERSUS RESOLUTION FOR WATER RESOURCES USE



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3. Achievement of the required performance thus requires principally improvements in discrimination capabilities.

As regards the frequency of repetition, current ground-based or aerophotographic surveys are repeated at intervals of several years; snow area, where it is performed, is currently effected at least every year: on important watersheds, more frequently through aerial means. This is consistent with the accuracies of current models.

This infrequent repetition must of necessity lead to the assumption that the watershed properties remain constant with time. In reality, the seasonal vegetative changes strongly influence the runoff, even at constant rains. The drive for increased precision in hydrologic modeling will eventually require that watersheds be imaged at different seasons, to take into account the changes in surface cover.

Table 5 recapitulates the current and future user requirements addressable from remote sensing.

Table 6 estimates the earliest era of operational feasibility for the principal applications *to specifications tolerable by the users.*

TABLE 5

CURRENT AND FUTURE USER REQUIREMENTS FOR WATER RESOURCES

MEASUREMENT	ACCURACY ACHIEVED BY CONVENTIONAL MEANS	ACCURACY DESIRED IN 1980 TIME FRAME, PERCENT	CURRENT FREQUENCY OF REPETITION YEARS	REPETITION DESIRED IN 1980 TIME FRAME TIMES PER YEAR
Elevation	See Figure 41	SAME	5 - 20	1/5
Area of Smallest Watershed Features	90 - 95	95 - 98	5 - 10	4
Discrimination & Identification of Areas	95	98	5 - 10	4
Streamwidth	Small users 0.1-0.25 meters Large users 1 - 3 meters	SAME	5 - 10	1
Streamlength	∿500 - 1000 meters	250 - 500 meters	5 - 10	1
Snow Area	90	98	none to 0.3	3 to 6
Flooded Area	±5 meters up to 100 meters ±100 meters above 1,000 meters	±2 meters ±10 meters	5 - 10	1 to 2 (to image major rivers
Wetland Area	95 - 97	98 - 99	3 - 10	2
Water Pollution Content	90 - 95	95 - 98	AD HOC	4 to 6
Water Pollution Pattern	NO SPEC.	90	AD HOC	AS FREQUENTLY AS POSSIBLE
Irrigated Area	90 - Limited Number of Regions	95	1	4 - 6
Soil Moisture	No Spec. Seldom Done and Ad Hoc	90	AD HOC	4 - 6

TABLE 5 (cont'd)

MEASUREMENT	ACCURACY ACHIEVED BY CONVENTIONAL MEANS	ACCURACY DESIRED IN 1980 TIME FRAME, PERCENT	CURRENT FREQUENCY OF REPETITION YEARS	REPETITION DESIRED IN 1980 TIME FRAME TIMES PER YEAR
Snowmelt Propensity	No Spec.	90	AD HOC	4 - 6
Evapotranspiration Measurements	85 - 90	90 - 95	MONTHLY-SEASONALLY	4 - 6
Cloud-Precipitation Correlation	in research	80 - 90	Research	As frequently as possible - even daily
Storage Waterworks Siting				
a) Topography & physical properties	N.A.	Not possible from SRS - Requires Stereo	AD HOC	NA
b) Environmental Impact	N.A.	80 - 90 for major parameters	AD HOC	AD HOC prior to construction 2 afterwards

TABLE 6

PRINCIPAL ADDRESSABLE FUNCTIONS IN WATER RESOURCES.

	EST. EARLIEST OPERATIONAL FEASIBILITY
Liquid Precipitation Measurement	
as input to hydrologic models	1985?
via DCP's	1975
Watershed Surface Mapping	
for hydrologic modeling	1976
Inundation Mapping	
for flood plain delineation (large rivers)	1976
Turbidity Spotting	
as a pollution indicator	1977
Wetlands Mapping	
institutional, reclamation, management	1977
Snow Depth Mapping	
for melt estimation	1985
via DCP's	1977
Snow Area Mapping	
for melt estimation	1978
Irrigated Area Mensuration	
as indicator of water demand	1979
Bay and Ocean Current Circulation and Diffusion	
to design pollutant effluxes	1980
Soil Moisture Mapping	
for estimation of irrigation demand	1982
via DCP's	1977
Storage Waterworks Siting	
to optimize reservoir cost/benefit	1982

Note: The first row under each heading refers to imaging. The second, to use of DCP's where applicable.

6. THE NETWORK OF PLAYERS IN WATER RESOURCES

In contrast to the situation in certain foreign countries, for example, England, where virtually all water resources activities are centralized, the U.S. water resources community is complex and fragmented. Also, many of the agencies perform overlapping functions. The principal agencies involved are shown in Table 7.

TABLE 7

AGENCIES ACTIVE IN WATER RESOURCES

Federal Agencies	
DOI-USGS	
USDA-ARS	
USDA-SCS	
USDA-FS	
NOAA	
DOI-Bureau of Reclamation	
COE	
EPA	
Other Federal: Bonneville Power, TVA	
States	50
State Water Resources Institutes	50
Major Universities	70
Local Governments	3,000
Private Contractors	3,000

Table 8 presents the principal operational activities of these agencies: in order to gage the emphasis of activities, their corresponding budgets are also given.

In addition to these operational activities, water resources agencies engage in research activities, primarily aimed at the development of hydrologic models of various types. The funding for this research by principal Agencies is presented in Table 9.

TABLE 9

YEARLY BUDGETS (FY1975) OF THE PRINCIPAL AGENCIES ENGAGED IN DEVELOPING HYDROLOGIC MODELS

	$ M
ARS	4.4
SCS	19.6
NOAA	4.2
FOREST SERVICE	1.9
USGS	2.1
BUREC	2.5
EPA	1.2
COE	2.8
TVA	0.3
TOTAL FEDERAL	39.0
STATES (EST)	5.0
LOCALS (EST)	5.0
	49.0

TABLE 8

AGENCY FUNCTION AND BUDGET, MILLION $FY1976, FOR CURRENT ACTIVITIES AMENABLE TO REMOTE SENSING

FUNCTION	USGS		SCS		ARS		FS		NOAA		BUREC		COE		EPA		BPA		TVA		S & L*		MOST LIKELY REMOTE SENSING TECHNIQUE
	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	F	B	
Precipitation Rain/Snow							X		X	17							X						DCP
Water Quality	X				X	1	X				X		X	2	X	1.2					X	4	DCP
Surface Water Flow	X	60			X		X		X	1	X		X	4			X		X	1	X	1.5	DCP
Ground Water Level	X							2			X												DCP
Snow Water Equivalency			X				X						X	0.3			X	2					DCP
Flood Mapping	X	2										5.4	X	200							X	3	SRS
Wetlands Mapping				1.5																	X	2	SRS
Snowcover Area			X				X		X	1			X	0.3			X						SRS
Water bodies Inventory											X		X	0.4									SRS
Turbidity Spotting			X																		X	1	SRS
Current Pattern									X	3													SRS + DCP
Irrigated Area																						1	SRS
TOTAL		62		1.5		1		2		22		5.4		27		1.2		2		1		12.5	137.6

NASA—MSFC

*States & Local F = Function B = FY1976 Budget

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